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TECHNICAL REPORT ECOM-00164-F

CONTINUOUS FACSIMILE SCANNER EMPLOYING FIBER OPTICS

FINAL REPORT

BY

D. A. PONTARELLI, R. SCHWAB, K. NORIKANE

JULY 1969

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IIT RESEARCH INSTITUTE
10 West 35 Street
Chicago, Illinois 60616

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CONTINUOUS FACSIMILE SCANNER EMPLOYING FIBER OPTICS

FINAL REPORT

24 JUNE 1964 to 31 JULY 1969

Report No. 55

CONTRACT DA28-043 AMC-00164(E)

Prepared By

D. A. PONTARELLI, R. SCHWAB, K. NORIKANE

IIT RESEARCH INSTITUTE
10 West 35 Street
Chicago, Illinois 60616

For

U. S. ARMY ELECTRONICS COMMAND, FORT MONMOUTH, N. J.

ABSTRACT

Fiber optics has been successfully employed to perform the functions of image dissection and scanning in Facsimile Transmission. Two operational models have been developed and constructed on this program to incorporate the concept. One was designed to scan copy 8 1/2-inches wide, the other, 18 5/8-inches wide. Both instruments possess the unique capability of continuously scanning copy of any length.

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LIST OF FIGURES

I. INTRODUCTION

This is the final report on Contract No. DA28-043-AMC-00164(E) dealing with the design and construction of two advanced development models of a continuous facsimile transmitter employing fiber optics for image dissection. The transmitters have the capability of continuously scanning copy of any length and generating a signal which is suitable for conversion to reproduced copy on a conventional GXC-5 Facsimile Recorder. The first instrument developed was designed to scan copy, nominally, 8-1/2 inches wide, and the second instrument, copy 18-5/8 inches wide. However, both instruments are open-throated so that copy wider than the scan area can be fed through them.

Photographs of the two instruments developed on this program are shown in Figure 1.

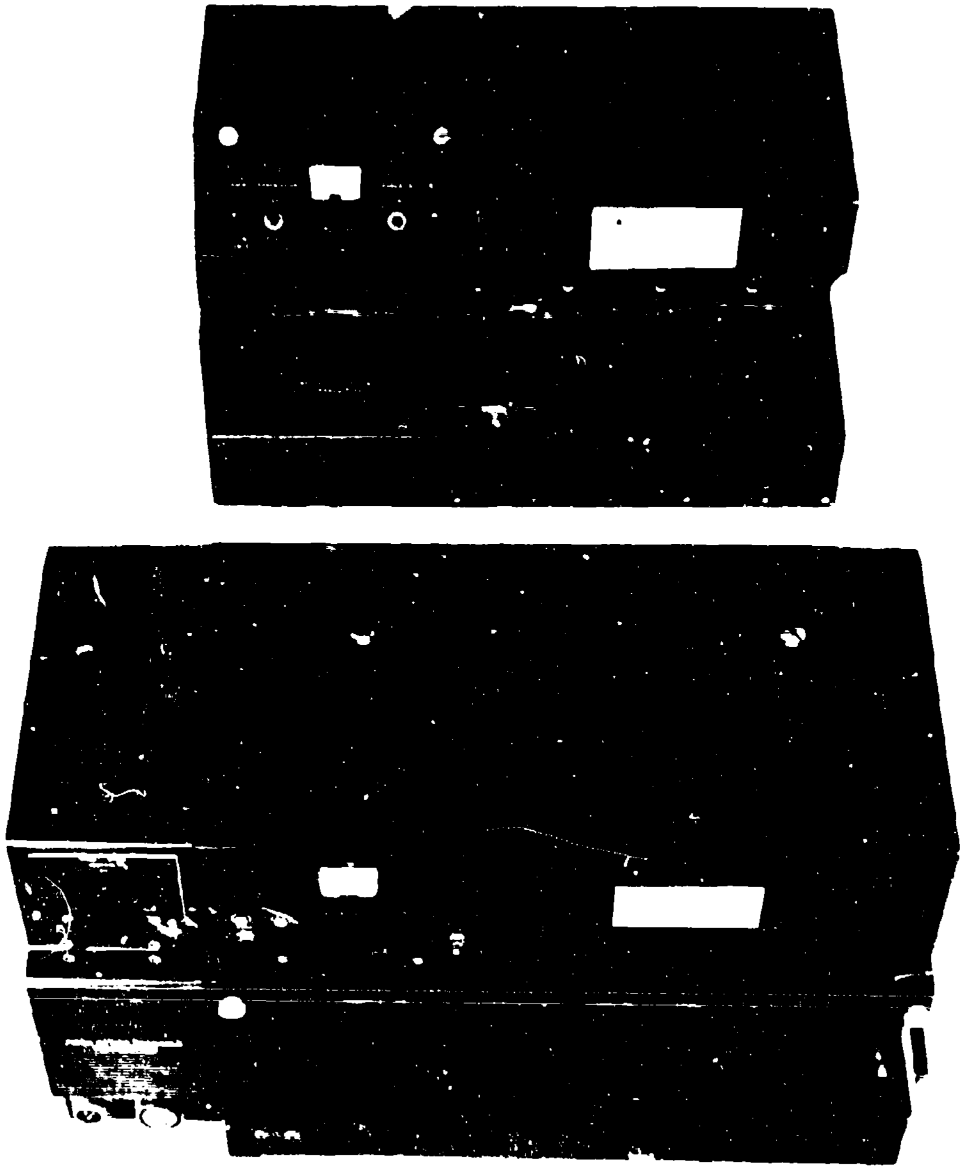


FIGURE 1. 8 1/2-INCH AND 18 5/8-INCH FIBER OPTICS FACSIMILE TRANSMITTERS

II. THEORY OF FIBER-OPTICS FACSIMILE

Scanning in conventional facsimile systems is usually accomplished by oscillating mirrors or rotating drums. In the former, the copy is mounted on the surface of a platform and flood-lighted. A detector aperture is imaged by an optical system, which includes the oscillating mirror, onto a small resolution spot on the copy. A line scan is generated by each oscillation of the mirror, and progressive line scans are generated by moving either the copy platform or the entire optical-detector system orthogonally to the line scan. If the copy is mounted on a flat surface this system results in a variable sized resolution element as the scan progresses from the center to the edge. Consequently, it is used only with narrow copy, or the copy can be mounted on a curved surface.

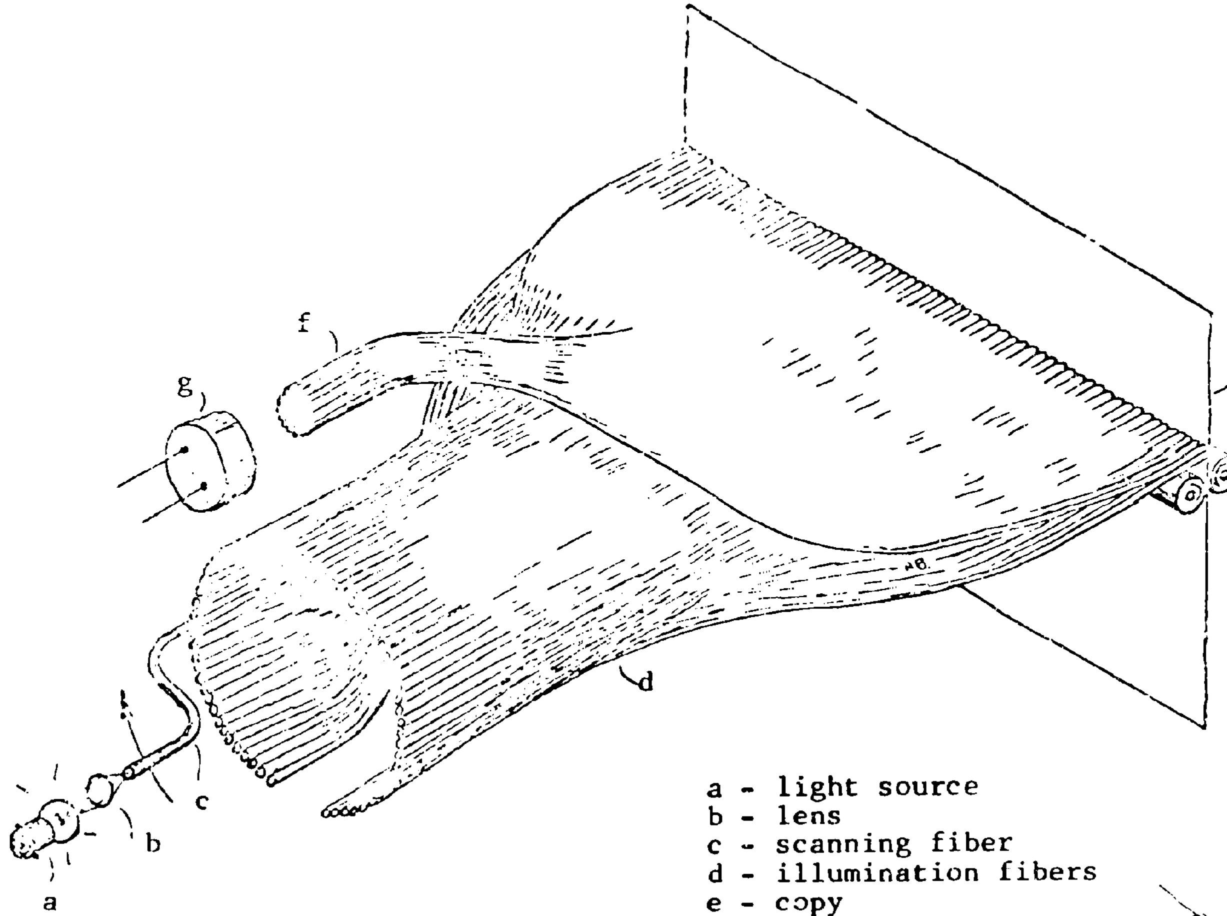
In the rotating-drum system, the copy is wrapped around a drum and flood-lighted. An optical system images a detector aperture on the surface of the copy to produce the resolution element. Rotation of the drum generates a line scan, and relative axial motion of the drum and detector-optical system generates progressive line scans. The chief disadvantage of this system lies in the fact that the copy must be clamped to the drum which, in addition, imposes restrictions on the copy dimensions.

The concept of fiber-optics image dissection is illustrated in Figures 2 and 3. Basic to this concept is an orderly linear-to-circular arrangement of a large number of fibers, approximately 2300 and 5300 for the 8-1/2 inch and 18-5/8 inch instruments, respectively. When the linear array is mounted in close proximity to the copy, each fiber determines a small resolution element, and the line of fibers defines a line of discrete adjacent elements. A line scan is then accomplished by rotating a crank-shaped fiber mounted on the axis of the circular array.

The crank-shaped fiber may be used either to transmit illumination to the copy from an axially mounted source or to transmit photometric information from the copy to an axially mounted photo detector. For reasons discussed in detail in Section III, the former mode was utilized in the transmitters developed in this program. A small spot of light is "scanned" across the width of the copy from left to right at a fixed number of scans per second.

The acquisition of photometric data is accomplished by two independent linear arrays mounted on either side of and in close proximity to the illumination array. The fibers from the two acquisition layers are gathered into a compact bundle as shown in Figure 2. A photodetector is mounted at the end of this bundle to receive the photometric information.

FIGURE 3. FIBER-OPTICS CONFIGURATION (8 1/2-INCH)



a - light source
b - lens
c - scanning fiber
d - illumination fibers
e - copy
f - pick-up fibers
g - detector

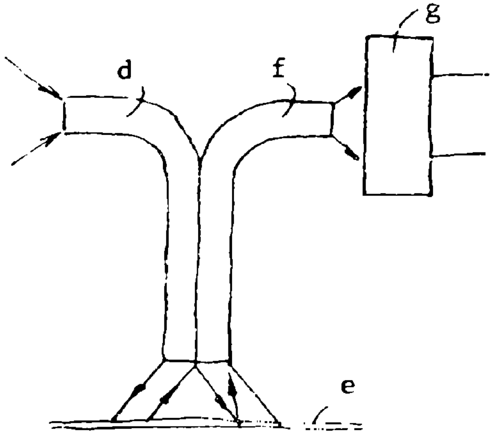


FIGURE 2. FIBER OPTICS FACSIMILE CONCEPT

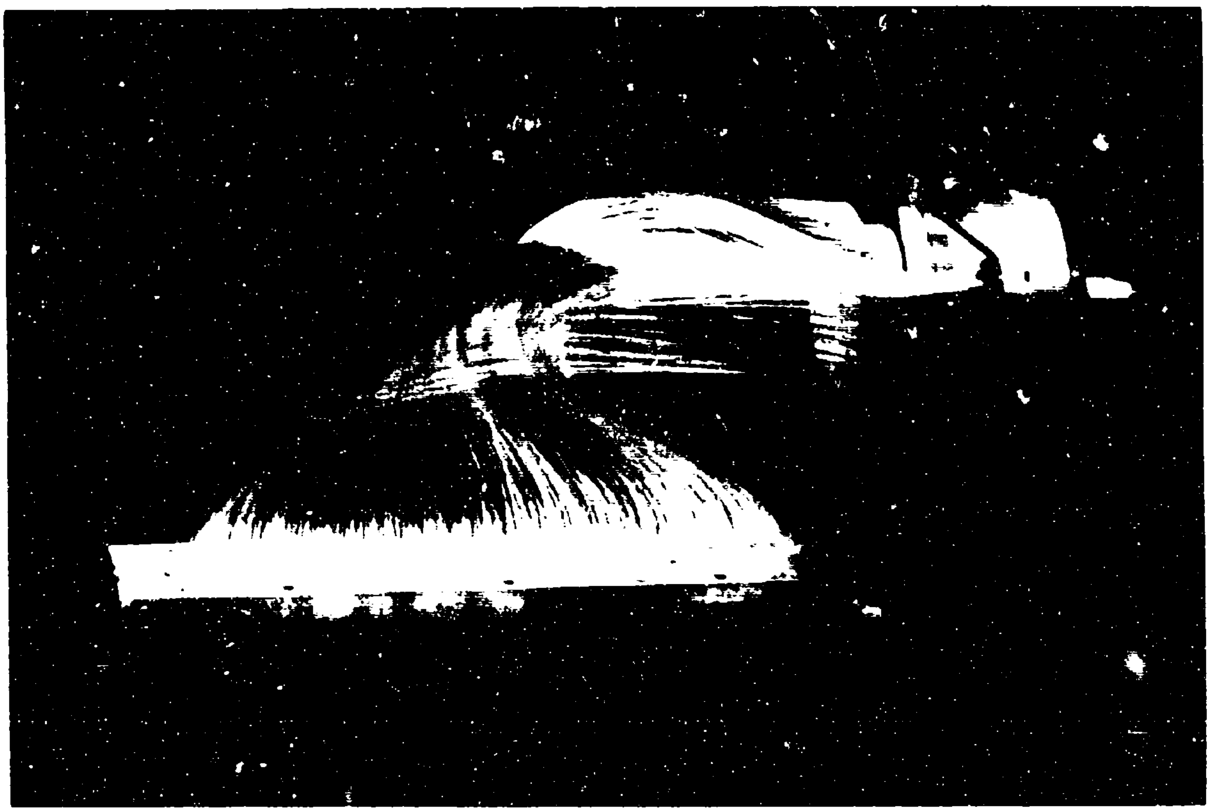


FIGURE 3. FIBER-OPTICS CONFIGURATION (8 1/2-INCH)

III. TECHNICAL DISCUSSION

A. OPTICS

1. Theory of Fiber Optics

The conduction of light by a transparent dielectric cylinder is due to multiple total internal reflections. If the cylindrical surface is clean and free from imperfections, all rays which enter one end will be trapped within the cylinder and emerge from the other end. For a clean, uniform and straight fiber, the only loss is that produced by absorption in the medium. Furthermore, the incident cone of light is preserved, in spite of the multiple reflections, so that the emergent cone subtends the same angle as the incident cone.

Freshly drawn glass fibers closely approximate the conditions assumed in the above discussion, but they will not retain these properties for any length of time in typical environments. Atmospheric fumes containing grease and dust will inevitably produce a coating which scatters light out of the cylinder and destroys the trapping effect described. The problem is solved by coating the fiber with a different glass, the refractive index of which is lower than that of the core material. Dirt which accumulates on the coated fibers will have no effect on the interface properties which are essential to the total internal reflections. Coating also eliminates "crosstalk" or interchange of energy between fibers when they are brought into close proximity. They are said to be optically insulated.

Coating is best accomplished in the fiber drawing operation. The core material as a rod is supported inside of a hollow tube of the coating material, and the two are introduced to a vertical furnace. As the glass softens, the two materials fuse and are drawn as a coated fiber. Obviously, the two materials must be compatible with respect to coefficient of expansion. A perfect match is not necessary, but when a mis-match prevails, it is preferable that the coefficient of the core be greater than that of the coating because stronger fibers are obtained.

The adjustment of refractive indices of core and coating provides a control over the numerical aperture of the fibers. Numerical aperture is a measure of the cone of light which is accepted and transmitted and is defined as the sine of one half the plane angle of acceptance. For a coated fiber with indices, n_1 and n_2 $(n_1 > n_2)$, the numerical aperture is given by the expression[2]

$$N.A. = \sin \theta = \sqrt{n_1^2 - n_2^2} \quad (1)$$

Clearly, the numerical aperture decreases as n_1 and n_2 approach equality. This is illustrated by numerical examples in the following table.

TABLE

NUMERICAL APERTURE OF REPRESENTATIVE GLASS COMBINATIONS

n_1	n_2	N.A.	θ
1.5	1.0	1.000	90.0°
1.62	1.52	0.555	33.5°
1.5	1.45	0.39	23.0°
1.56	1.52	0.36	21.0°
1.54	1.52	0.245	14.0°

It should be noted that Formula (1) gives the expression for numerical aperture when the respective materials are essentially non-absorbing. The numerical aperture will be smaller than the value given by the formula if the coating material is absorbing. The explanation for this is to be found in the nature of reflection at an interface. Although the latter is usually described as an interface phenomenon, actually there is a slight penetration (of the order of the wavelength of light) into the second medium and, if that medium is absorbing, some light will be absorbed at each reflection. Furthermore, the amount of penetration is a function of the angle of incidence, being greater for rays making greater angles with the interface. Accordingly, after many internal reflections, the higher angle rays, externally, are attenuated more and the numerical aperture is effectively reduced. This effect is not readily expressed analytically but it is obvious that it depends on the absorption coefficient of the coating and the length of the fiber. The numerical aperture decreases with increasing coefficient of absorption of the coating and with increasing length.

2. Three-Layer Fiber-Optics Probe

The optical probe of the fiber-optics scanner is a three-layer linear scan bar, as pointed out in Section II and illustrated in Figure 2. The intermediate layer of fibers is the illumination layer; a spot of light is "scanned" across the copy at a fixed number of scans per second. The reflectivity of the copy under the spot of light governs the amount of light which is reflected into the fibers of the pick-up layers.

It was pointed out in Section II that the crank-shaped fiber may be used in either of two ways: (1) conduct light from an axially mounted source to the circular array and thence to the copy or, (2) conduct light from the copy to an axially

mounted photodetector. The former mode, (1), was utilized in both of the scanners of this program. The two modes are equivalent as regards optical resolution but require different optical implementation. In Mode (1), the detector faces the compact bundle and must have a relatively large sensitive area, whereas the light source may have a small area since it faces the small area of the crank-shaped fiber. In Mode (2), the reverse is true, the source must be broad and uniform to fill the compact bundle whereas the detector may have a small area.

In the present program, the choice of mode was dictated by constraints imposed by practical considerations. A photomultiplier detector could not be used because of its extreme susceptibility to R.F. interference. A multiplier-type detector is very sensitive, being several orders of magnitude better than any other type. Its rejection, therefore, made it necessary to design a system around a detector with relatively low sensitivity. Consequently, a high-brightness source would be required. The broad source such as a fluorescent bulb required by Mode (2) is, inherently, a low-brightness source. A high-brightness source is inherently of small area in low wattages. Mode (1), in which the source need only illuminate the end of the single crank-shaped fiber, was therefore the only possibility.

In Mode (1), the sensitive surface of the detector must be large enough to accept the light emerging from any fiber of the compact bundle. The diameter of the latter is approximately 0.25 inches in the 8-1/2 inch instrument, and 0.38 inches in the 18-5/8 inch instrument. The light emerging from the end of the compact bundle diverges at 34°, determined by the numerical aperture (NA) of the fibers. This light falls on an area of the detector the diameter of which is given by the expression,

$$D = d + 2h \tan 34° = d + 1.35h \qquad (2)$$

where D = diameter of circular area on detector
d = diameter of compact bundle
h = distance from end of compact bundle to detector surface.

When h = 1/4 inch, D = 0.588 inch for the 8-1/2 inch scanner, and 0.718 inch for the 18-5/8 inch scanner.

When h = 1/2 inch, D = 0.925 inch for the 8-1/2 inch scanner, and 1.055 inches for the 18-5/8 inch scanner.

For mechanical reasons, the spacing, h, must lie in this range. The sensitive area of the detectors used in the transmitters has a diameter of approximately 1-1/2 inches.

3. Scan Resolution

The resolution capability of the fiber optics facsimile scanner is established by the optical properties of the fibers and their geometric arrangement at the linear scan bar and circular array. The static resolution orthogonal to the scan

line direction may be treated by referring to Figure 4 which shows a section through a three-layer fiber-optics image dissector. Illumination brought to the copy by the middle fiber layer is reflected by the copy and collected by the two outer fiber layers. In this discussion the numerical aperture of the illumination and flux-collecting fibers will be denoted by $(NA)_I$ and $(NA)_c$, respectively, where $(NA)_c > (NA)_I$, their diameters by d_I and d_c, and the fiber-end-to-copy distance by h, assumed to be the same for all fibers.

The diameter of the spot illuminated on the copy is given by

$$D_I = d_I + 2h \tan \sin^{-1} (NA)_I \tag{3}$$

and the diameter of the collection spot by

$$D_c = d_c + 2h \tan \sin^{-1} (NA)_c \tag{4}$$

To maximize the collection of flux reflected by the copy in the illuminated spot, the latter must be completely contained within the collection spot. This condition can be expressed in terms of the diameter of the collection spot by reference to Figure 4, and is

$$D_c = d_c + 2k + 2d_I + 2h \tan \sin^{-1} (NA)_I \tag{5}$$

in which k is the spacing between fiber cores.

Equating the two expressions for D_c given in Equations (4) and (5) yields the expression,

$$h \tan \sin^{-1} (NA)_c = k + d_I + h \tan \sin^{-1} (NA)_I \tag{6}$$

from which the $(NA)_c$ necessary to satisfy the condition can be determined.

For the case of a 96 lines/inch scanner using 0.003-inch diameter and 0.56 numerical aperture fibers for illumination, the copy-to-fiber-end separation, h, is found by Equation (3) to be 0.005 inch. If the fiber layer separation, k, is taken as zero, the munerical aperture of the collection fibers is found by Equation (6) to be $(NA)_c = 0.77$. This system could be fabricated from core and coating glasses currently available.

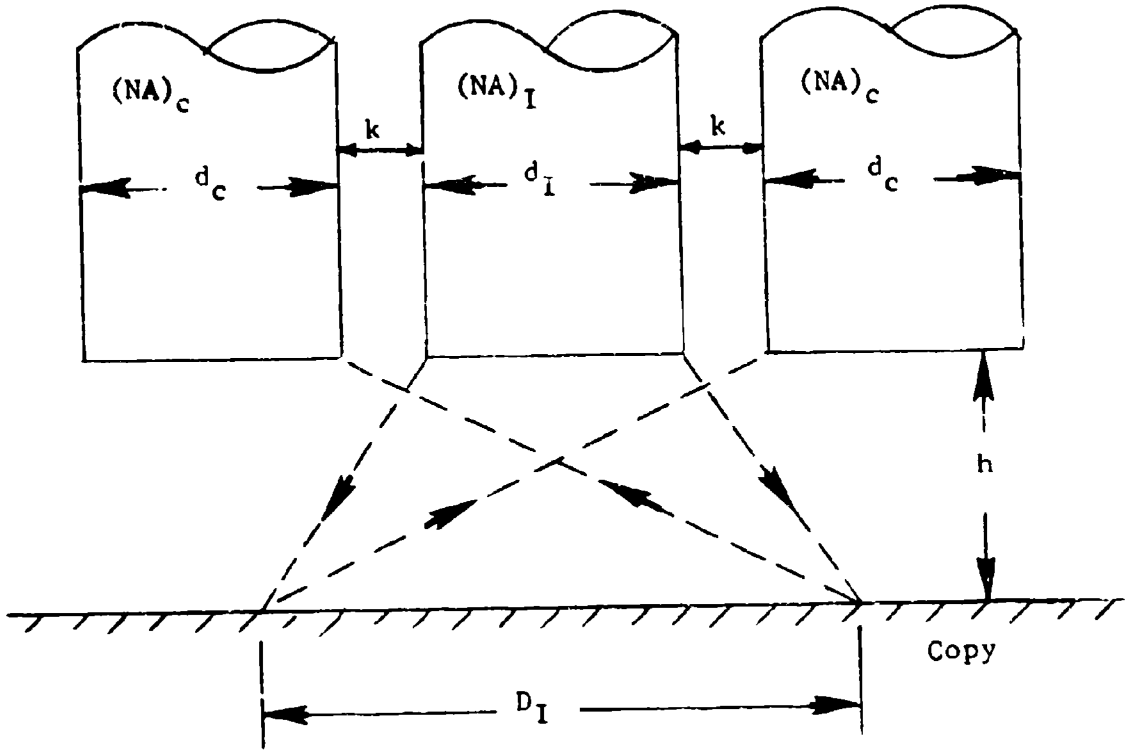


FIGURE 4. CROSS SECTION OF LINEAR SCAN BAR FIBERS.

Although a complete overlap of the illumination spot by the collection spot is desirable from the point of view of efficiency, the large value of $(NA)_c$ required for its accomplishment creates a serious problem at the detector end of the collection bundle. A numerical aperture of 0.77 corresponds to a 50° emergent cone angle, or 100° total divergence of the emerging beam. This would require an unduly large sensitive surface unless the latter could be moved very close to the exit bundle, which was impossible. For this reason, identical fibers (diameter, d=0.003 inch; NA = 0.56) were used for both the illumination and collection functions in the scanners. In this case the over-lap, δ, of D_I and D_c can be shown to be

$$\delta = \left(\frac{D_I + D_c}{2}\right) - d - k \qquad (7)$$

The conditions for $D_I = D_c = 0.0104$ inch, h = 0.0055 inch and k = 0.001 inch are illustrated in Figure 5. The computed value of δ is 0.0064 inch. The overlap of the previously described system was 0.0104 inch. Therefore, in terms of diameter ratios, the second system has an efficiency of 62%. The area common to the illumination and collection circles is

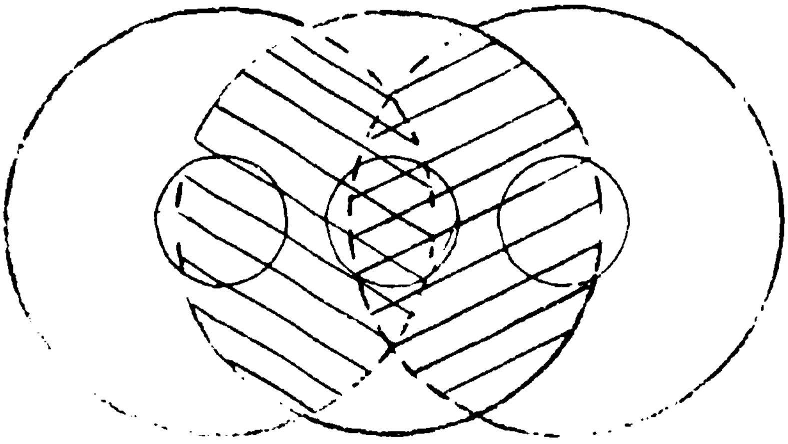
$$A_{common} = \frac{\pi D_I^2}{4} - \frac{1}{2}\left[(D_I-\delta)(2D_I\delta-\delta^2)^{1/2} + D_I^2 \sin^{-1}\left(\frac{D_I-\delta}{D_I}\right)\right] \qquad (8)$$

when the circle diameters are the same. The efficiencies of the two scanners are more correctly compared by taking the ratio of the overlap areas in the two systems giving

$$Eff_1 = \frac{A_{D_c>D_I}}{A_{D_c=D_I}} = 23\%$$

4. <u>Photometric Properties</u>

In the previous section the resolution and areas common to detection and illumination fibers were discussed only in terms of the geometry of the illumination and collection fibers, the desired resolution, and the area common to the illumination and collection circles in the plane of the copy. In the present section, photometric relationships will be developed. For this discussion, it will be assumed that the diameter of the fiber is comparable with the fiber-end-to-copy separation and that the illumination from the illumination fiber has uniform angular distribution.



TOP VIEW

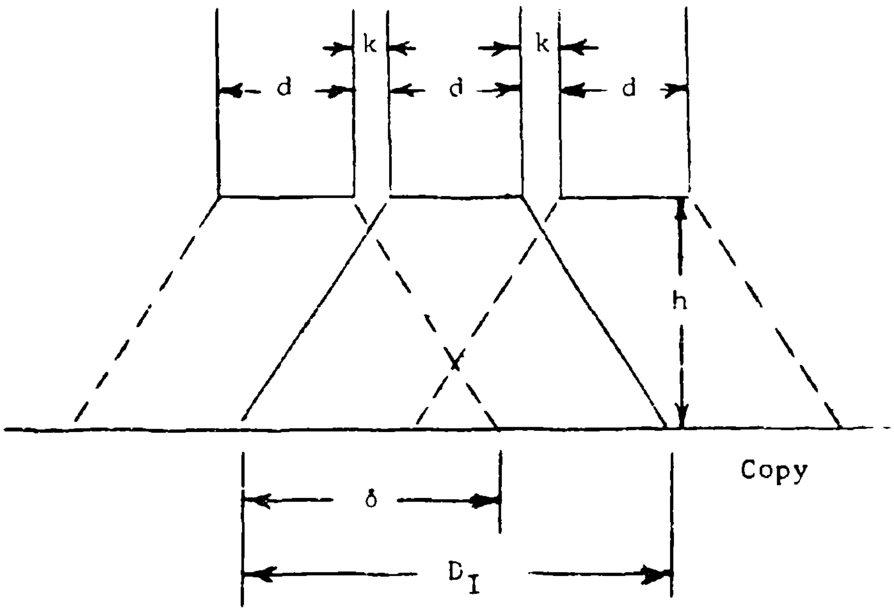


FIGURE 5. TOP AND SIDE VIEW OF SCAN BAR CONFIGURATION (DRAWN TO SCALE)

The illumination at the copy, E_c, for a separation, h, a fiber of brightness, B, and diameter, d, is given by

$$E_c = \frac{B\pi d^2}{4h^2 + d^2} \tag{9}$$

which shows that the illumination of the copy increases when h is reduced or when d is increased.

The flux incident on the copy will, for most copy, be diffusely reflected. In this case the brightness of the illuminated copy is given by

$$B_{copy} = \frac{B\ d^2\ R}{4h^2 + d^2} \tag{10}$$

where R is the reflectivity of the copy.

The flux collected by a fiber of the diameter, d, at a separation, h, from the common area, A_{common} (Equation 8), is

$$\text{Flux Collected} = (A_{common})\ R\frac{B\pi d^4}{16h^2(h^2 + \frac{d^2}{4})} =$$

$$R\frac{B\pi d^4}{16h^2(h^2 + \frac{d^2}{4})}\left\{\frac{\pi D_I^2}{4} - \frac{1}{2}\left[(D_I - \delta)(2D_I\delta - \delta^2)^{1/2} + D_I^2 \sin^{-1}\left(\frac{D-\delta}{D_I}\right)\right]\right\} \tag{11}$$

This equation relates the variables significant to the photometric analysis of the image disector. First, consider d to be constant, and analyze the effect of changes in h on the collected flux. As h is decreased from the optimum value of 0.0055 inch for a resolution of 96 lines/inch, the common-area term in brackets decreases as the square of h while the denominator decreases approximately as the fourth power of h. Therefore, the optimum value of h for maximum collected flux is less than the value h = 0.0055 inch. The best value of h determined by experimentation was found to be approximately 0.003 inches. This value is (1/1.73) of 0.0055 inches, and Equation (11) predicts an increase of flux by approximately a factor of three.

The above discussion treats the photometric properties of the fiber optics facsimile scanner in terms of meridional optics. In practice, light flux scattered from the copy is collected by approximately three adjacent fibers in each of the two collection fiber layers. The second-order effects attributed to these

additional collection fibers can be assumed to be small because of the larger h values and smaller subtended area of the collection fibers. The optimum value of $h = 0.003$ inches would result in a smaller scan spot and higher resolution; however, in practice, on the average two illumination fibers are active in scanning the copy and the desired 96 lines/inch resolution is obtained.

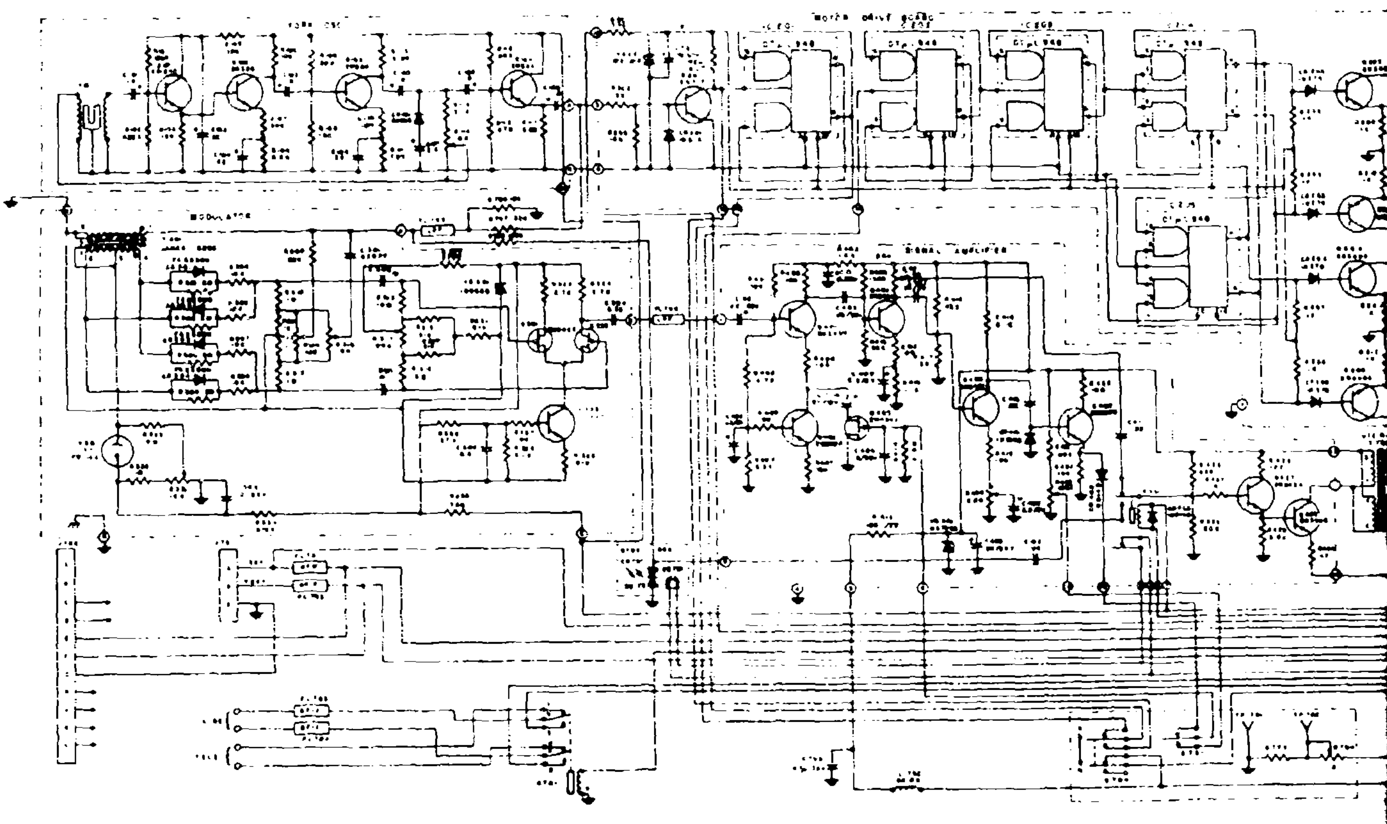
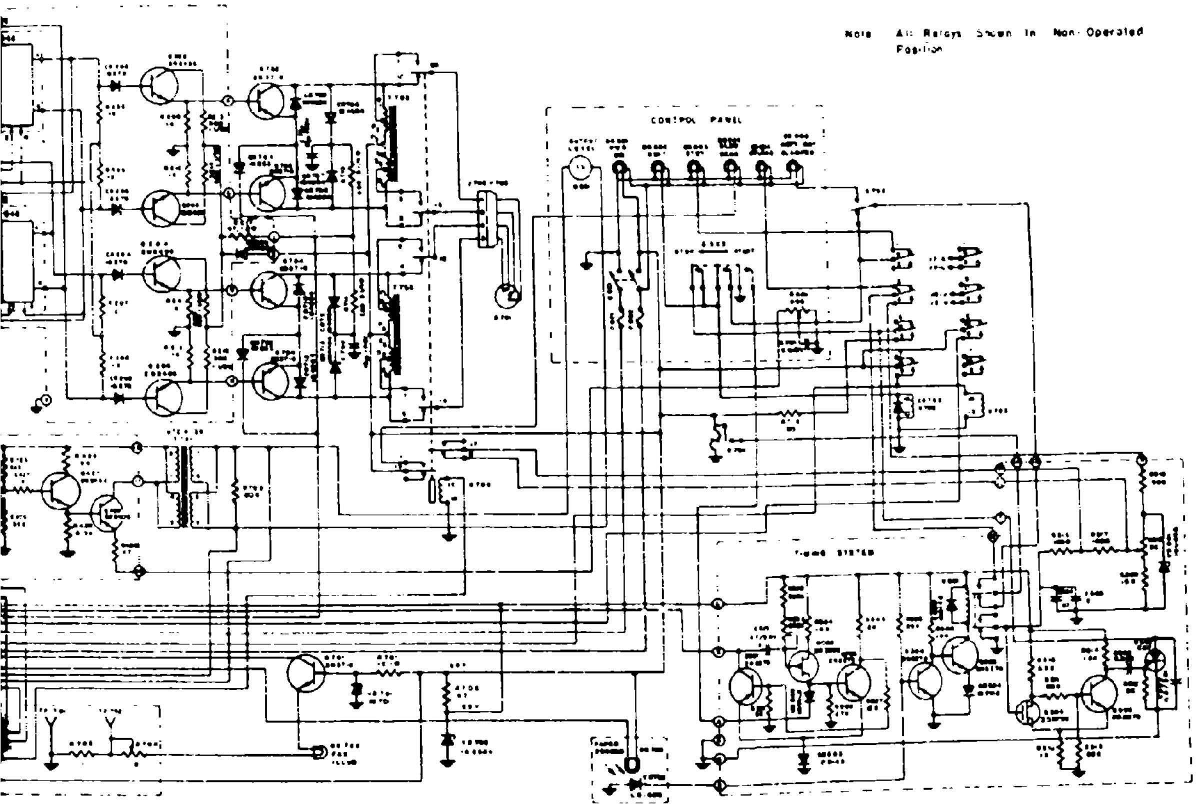


FIGURE 6. SCHEMATIC DIAGRAM OF 8 1/2-INCH FI



1/2-INCH FIBER OPTICS FACSIMILE TRANSMITTER

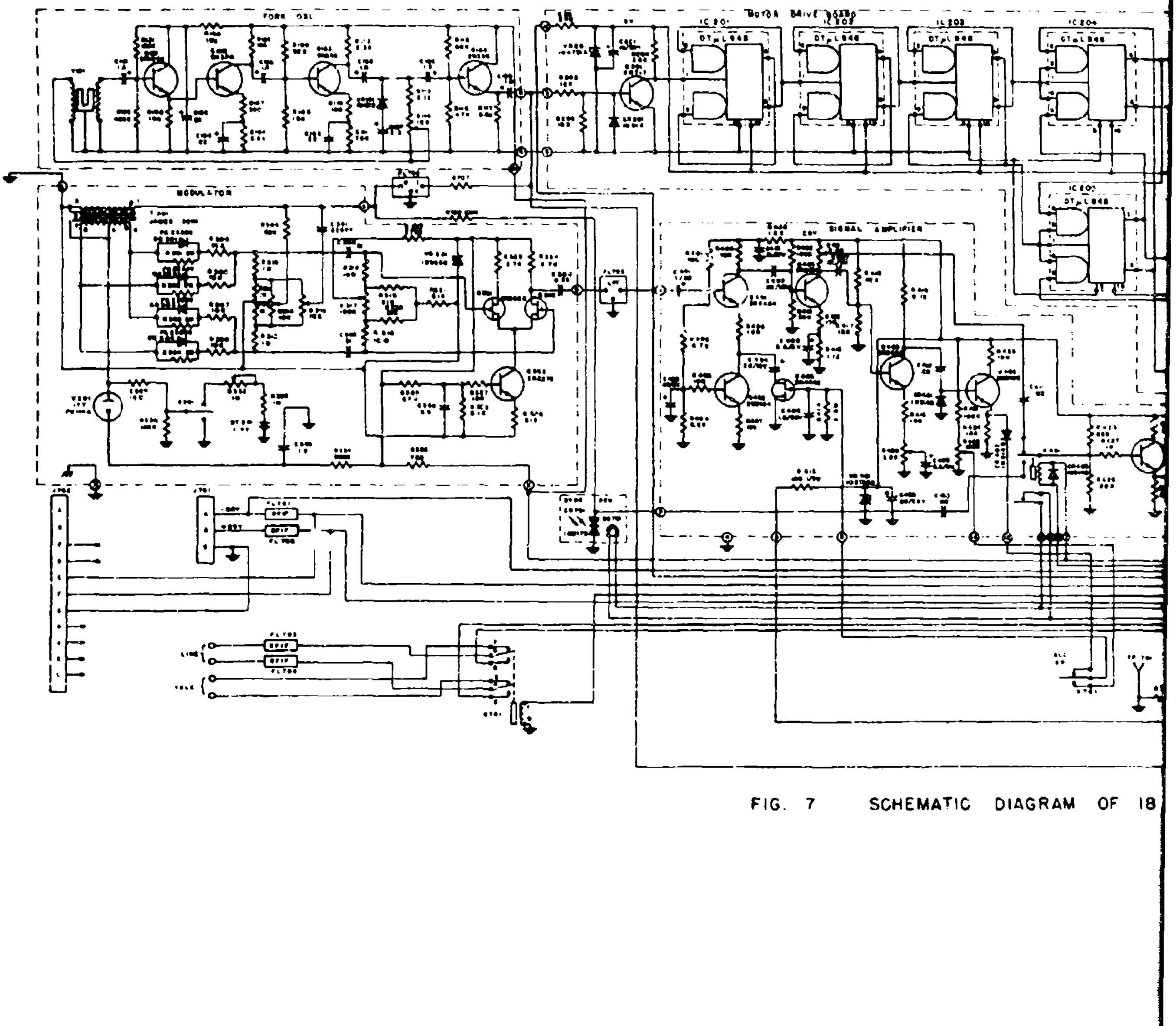
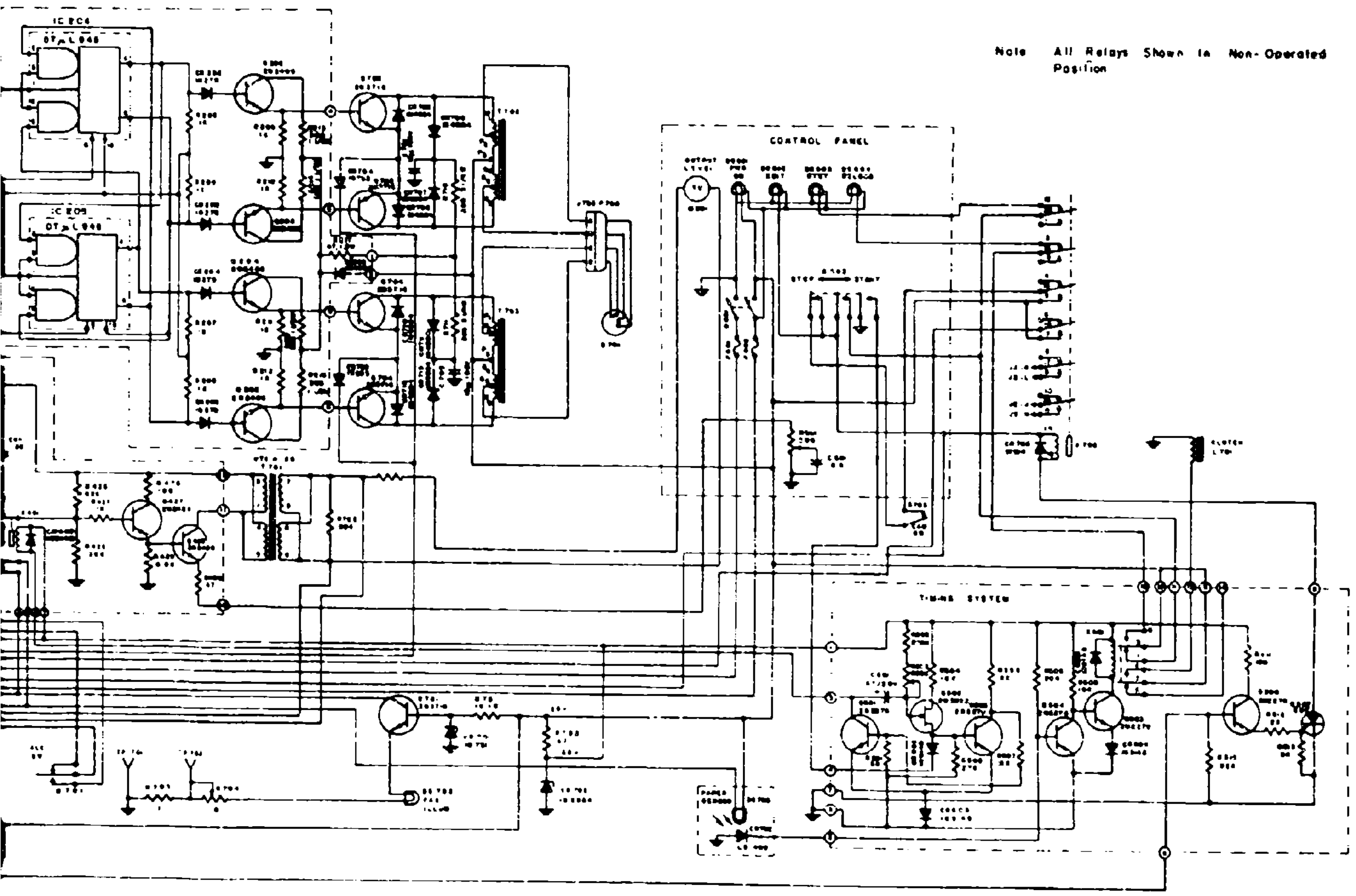


FIG. 7 SCHEMATIC DIAGRAM OF 18



GRAM OF 18 5/8" FACSIMILE TRANSMITTER

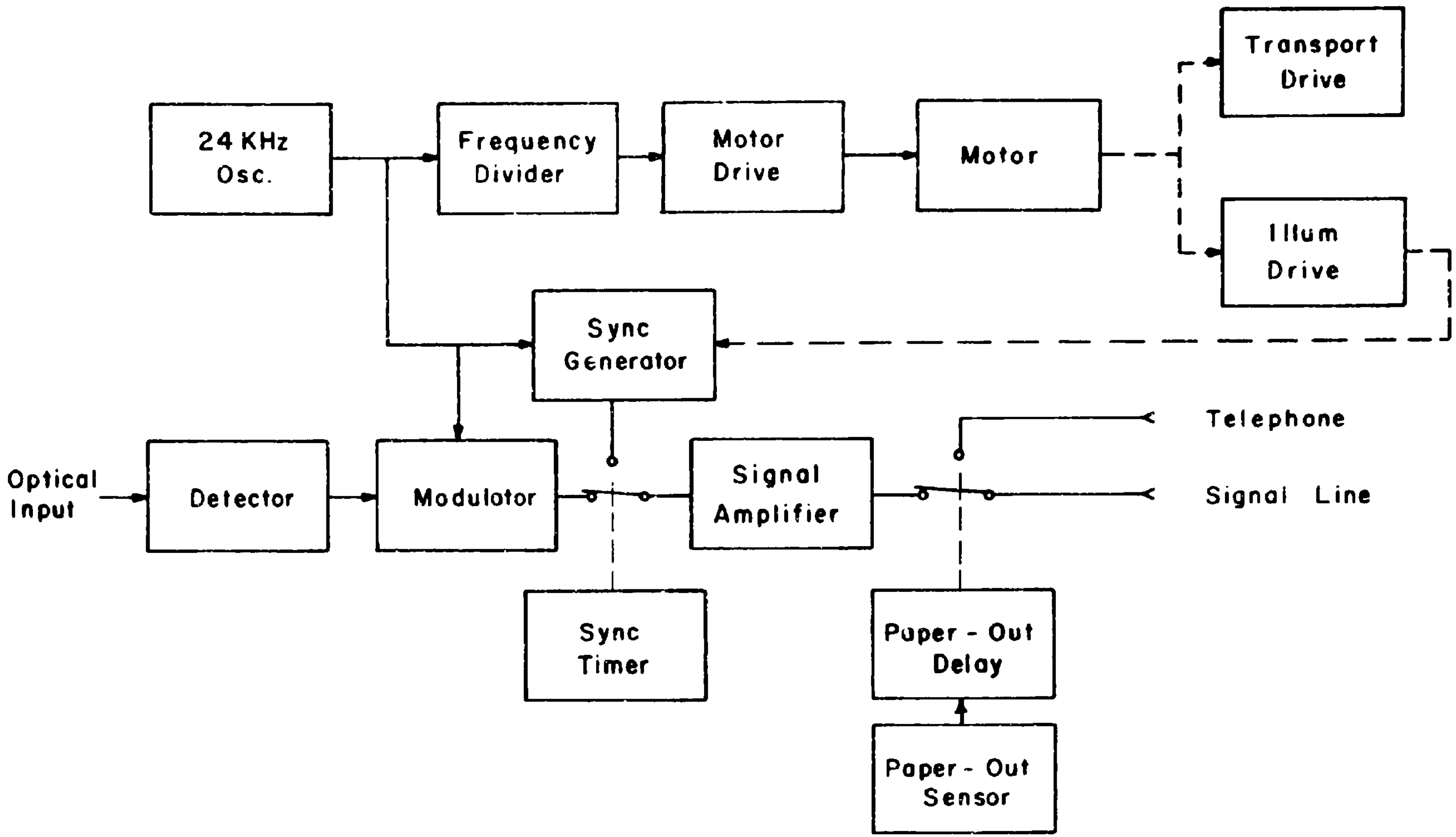


FIGURE 8. BLOCK DIAGRAM OF TRANSMITTER ELECTRONICS

B. ELECTRONICS

1. Introduction

The electronics design of the fiber optics facsimile transmitter was originally expected to consist of a re-packaging of the electronics of the existing AN/GXC-5 scanner. However, upon careful analysis of the modulation and amplification requirements of the fiber optics output, it became evident that much of the electronics would require complete redesign. The electronics design thus proceeded within the constraints of the optical input from the fiber-optics image dissector and the control functions and input signal characteristics required by the AN/GXC-5 receiver. The optical input from the image dissector consisted of a series of low-level cones of light emitted from the end of the compact bundle of pick-up fibers. The requirements of the AN/GXC-5 receiver consisted of the following:

1) Stability consistent with that of the 2400 Hz fork frequency oscillator of the AN/GXC-5.

2) Transmission consisting of a phasing period, transmission of copy of arbitrary duration, and a stop signal. The phasing period should consist of a 2.4 kHz signal interrupted for a duration of 13 milliseconds prior to each scan across the copy. The stop signal should consist of removing the 2.4 kHz from the signal line.

3) The output signal should be a balance-modulated 2.4 kHz carrier whose level is adjustable between -10 dbm and +5 dbm. The output impedance should be 600Ω balanced on ground.

The electronics protion of the 8 1/2-inch and 18 5/8-inch fiber-optics facsimile transmitters of Figure 1 are essentially the same, as can be seen by an examination of their respective schematic diagrams in Figures 6 and 7. The primary difference in the electronics results from the requirements of scanning rates of 60, 90 and 120 scans/minute on the 18 5/8-inch transmitter and a 90 and 180 scans/minute on the 8 1/2-inch transmitter. Thus, a mechanical speed change was employed in the 18 5/8-inch instrument as opposed to an electrical speed change on the motor in the 8 1/2-inch transmitter. With the mechanical speed change, a clutch and cam arrangement was employed on the paper-out delay. The operation of the transmitter electronics can best be visualized from an examination of the block diagram of Figure 8. The stable 2.4-kHz fork oscillator is used to maintain synchronism with the receiver by means of a frequency divider which supplies the synchronous-drive motor with a 300/150 Hz drive current. At the initiation of transmission, the signal-amplifier input is transferred to

the phasing generator which supplies a 2.4 kHz signal which is interrupted for a duration of approximately 12 milliseconds immediately preceding each scan of the copy. The phasing period permits the phase of the transmitter copy illumination and the print heads of the receiver to become locked. At the end of the phasing period the signal-amplifier input is returned to the modulator output for transmission of copy. The paper-out delay is initiated by sensing the end of the copy at a point ahead of the transport belt. After the delay, the signal line is transferred to the telephone set, removing the modulated 2.4 kHz from signal line. The absence of this signal causes the receiver to terminate operation. The choice of the circuitry comprising the blocks of the diagram of Figure 8 as well as a detailed description of their operation is provided in Section 2 below.

2. Discussion of Circuitry

a. Oscillator

The choice of oscillator was determined by two factors. First, the oscillator frequency must be some multiple of 2.4 kHz since this carrier frequency is required for operation with the receiving equipment. Second, the oscillator stability must be equal to or less than one part in 200,000 which corresponds to 3/64-inch skew per 11 inches of copy. The Westrex fork oscillator, type FST-1, meets these requirements and was thus chosen. An additional reason for employing a fork oscillator rather than the more stable crystal oscillators is the extensive use of this oscillator in much of the receiving equipment. The operation of the oscillator circuitry of Figures 6 or 7 is described below.

The circuit diagram of the oscillator is seen in the upper left portion of Figure 6 or 7. The pick-up coil of the tuning fork is capacitively coupled through C101 to the base of an emitter follower which acts as a buffer stage to maintain the frequency stability of the fork. The output from the emitter of Q101 is fed directly into the base of Q102 which amplifies the 2400 Hz current variation in the emitter. The amplified signal is coupled through capacitors, C103 to Q103, which operate as a power amplifier. It is then capacitively coupled to a limiting circuit which clips the peak of the signal to produce a square wave. A part of this signal is fed through a fixed resistor, R113, and a variable resistor, R114, to the driving coil of the tuning fork to satisfy the requirements for oscillation. The remainder of the signal is emitter-follower coupled. The emitter-follower circuit acts as a buffer presenting a high impedance to the diode-limiter circuit, and a low impedance to the motor drive and signal-electronics circuitry.

b. Transport Drive

Because of stability requirements discussed above, the oscillator 2.4 kHz was divided down to 300 or 150 Hz to provide a power source with stable frequency for the motor. The divider circuit consists of a chain of 5 integrated-circuit flip-flops. In the 18 5/8-inch unit, all 5 flip-flops are used continuously; while in the 8 1/2-inch unit, the first flip-flop is normally by-passed except when the slow speed (90 scans/minute) is desired. The final two flip-flops in the divider are driven in parallel off the two collectors of the third flip-flop (IC203 of Figures 6 and 7) resulting in two outputs which are always 90° out of phase with each other. This system has the advantage of always maintaining the 90° phase shift independent of the current required by the drive circuitry. The drive transistors are directly coupled to the power transistors which allow them to be driven from saturation to cut-off to minimize power dissipation in the drive circuit. It is, however, somewhat questionable if the efficiency of the system is increased by this since the higher harmonics of the drive current do not produce power in the motor and must be dissipated there. A disadvantage of the directly coupled drive is the danger of damaging the motor and/or power transistors if the oscillator stops, as excessive currents will be drawn through them. In normal operation, drive power is not applied to the drive transistors until the oscillator is operating. The transformers, T701, T702, and T703, are used to match the motor to the drive circuit since the hysteresis-synchronous motor is rated at 115v ac. The original design specified a low-voltage center-tapped, hysteresis-synchronous motor; however, after a lengthy delay the supplied motor was found unsatisfactory. Thus, an off-the-shelf motor was used because of the long deliveries quoted on special motors. The motor employed also has the disadvantage of being too large. This is due to the original requirement of an automatic slew function for rapid copy advance. This requirement was replaced by a manual copy advance after the motors were ordered. A detailed description of the circuit operation of Figure 6 or 7 is included below.

The fork-oscillator output drives transistors Q201 between saturation and cut-off to provide an input compatible with that required by the integrated-circuit flip-flops used in the divider circuit. The integrated-circuit flip-flops are connected to function in the J-K mode via the interconnection of pins 4 to 9 and 6 to 2. In operation, each integrated circuit functions as a pair of flip-flops. During the period when the clock pulse is in the 1 state (voltage above 1.2v), the voltage levels on pins 2 and 9 are used to set the state of the first (master) flip-flop, and the inputs to the second (slave flip-flop are inhibited. When the clock-pulse input voltage falls to the 0 state (voltage below 0.5v), the state of the master flip-flop is transferred to the slave flip-flop

and appears at the output on terminals 4 and 6 In this state, the input of the master flip-flop via terminals 2 and 9 is inhibited. Thus the flip-flop output changes state only on a 1 to 0 excursion of the input, resulting in a division by two in frequency between the input and output of each flip-flop. Therefore, in the slow-scan mode, the outputs of Q201, IC201, IC202, and IC203, are 2400 Hz, 1200 Hz, 600Hz, and 300Hz, respectively. The 1 output (pin 4) is used to drive IC205 while the 0 output (pin 6) is used to drive IC204. Flip-flops IC204 and IC205 function as the previous units, resulting in output frequencies of 150 Hz from both units. Since the clock-pulse inputs to IC204 and IC205 are 180° out of phase, the resulting 150 Hz outputs are 90° out of phase, providing the appropriate phase relationship to drive the two-phase motor. The operation of the 8 1/2-inch transmitter with switch, S704, in the NORM position is the same as above with the exception that IC201 is not used and thus the output frequency is 300 Hz rather than 150 Hz.

The output of the frequency-divider circuit at pins 4 and 6 from IC204 are square waves 180° out of phase, and at pins 4 and 6 from IC205, are also square waves 180° out of phase and 90° out of phase with those from the terminals of IC204. The outputs of IC204 drive Q202 and Q203 which are emitter followers which drive power transistors, Q702 and Q703, respectively. The collector circuits of Q702 and Q703 contain transformer T702, which functions as an auto-transformer. The dc supply is connected to P_3 and S_4 (one side of the primary and secondary windings, respectively) while the motor windings are connected between P_1 and S_6 for normal-speed operation, and between P_2 and S_5 for slow speed operation. Thus, due to the 180° phase shift between the two drive signals, terminal P_1 is grounded via Q702 while terminal S_6 is open during one half cycle of the drive signal and, conversely, S_6 is grounded via Q703 and P_1 is open during the alternate half cycle. The peak-to-peak voltage appearing across the motor winding is thus four times the supply voltage. The diodes, CR706 and CR707, in conjunction with C701 and R710, are used to limit the peak V_{CE} during switching. The operation of the drive circuitry for the other phase of the motor is the same as that described above.

c. Detector

The detector and electronics employed in the fiber-optics facsimile transmitter are quite different from those used in the conventional AN/GXC-5 instrument largely because of the vast differences between fiber optics and conventional optics. In the AN/GXC-5 a 0.010 inch x 0.010 inch illuminated area is fixed in position with respect to the detector and can, therefore, be imaged on the detector. The detector employed by the AN/GXC-5 is the RCA 5652, a dual-cathode photo tube with

the cathodes positioned to allow focussing 50% of the light from the illuminated area on each of the cathodes. Thus the 2.4 kHz voltage from the oscillator can be impressed across the photo cathodes and the resultant current is a measure of the copy reflectivity during either half cycle of the 2.4 kHz wave. A third electrode is enclosed within the tube envelope to provide a capacity balance in the modulator circuit. In the case of the fiber-optics transmitter, the reflected light transmitted by the pick-up fibers wanders about the compact end of this bundle as the copy is scanned. This feature makes it impossible to use the RCA 5652 tube as a detector.

The inability to use the RCA 5652 phototube made it necessary to search for available detectors whose viewing area, sensitivity, frequency response and linearily would be compatible with the requirements of the fiber optics output. The classes of detectors investigated included the silicon detector, photo transistor, vacuum photo diode and photo multiplier. The photo multiplier was seen to fulfill the above requirements but was rejected because of its susceptibility to shock and interference from electric and magnetic fields and its high-voltage requirement. Silicon detectors were tested in both the photo-conductive mode and the photo-voltaic mode. In the photo-conductive mode they possessed sufficient sensitivity, linearily, and frequency response but had a high dark current which became excessive at higher temperatures. In the photo-voltaic mode they exhibited a smaller change in sensitivity with increasing temperature but were found to have non-linear output as a function of illumination level. The phototransistor was also found to exhibit non-linearily as a function of illumination level, and temperature sensitivity. An additional disadvantage of the solid-state detectors is their unfavorable spectral sensitivity. In general, the peak of their spectral sensitivity lies near 0.8 microns and extends to 1.2 microns. This response, coupled with the spectral energy distribution of an incandescent light source, produces a system which is more sensitive in the near infrared than in the visible region. Since many inks possess a stronger reflectivity in the near IR than in the visible, the resultant visible-contrast sensitivity of the system is reduced. This was experimentally verified by measuring the reflectivities of several inks using standard photometric techniques and comparing the results with those obtained with the silicon detectors. The photometric measurements indicated a white-to-black ratio of 10:1 while the silicon detector yielded only a 3:1 ratio. Because of the above problems with solid-state detectors, a vacuum photodiode (ITT Industrial Labs FW114A) was chosen as a detector. The unit has a large-area photocathode with a sensitivity of 80uA/lumen and a very low dark current, but has the disadvantage of an anode grid on the face of the plate of the tube. The grid necessarily attenuates the light from some fibers more than others but this effect is reduced by increasing the spacing between the end of the pickup bundle and the tube face-plate.

d. Modulator

The modulator design was guided by the requirements of, first, a balanced modulator output centered at 2.4 kHz and, second, the ability to modulate with a constant optical input or a dc current into the modulator. Due to the low signal levels from the phototube (approximately 10^{-9} amp with a source impedance of 10 MΩ), some consideration was given to the use of a dc amplifier before modulation to reduce the balance requirements of the modulator. It was felt, however, that the low-level modulator balance capability would require less equipment than a temperature-stable, high-gain, low-level dc amplifier. Consequently, several balanced modulator designs were investigated, with that incorporated in the circuit diagram of Figures 6 and 7 operating best. The modulator designs of Figure 6 (8 1/2-inch transmitter) and Figure 7 (18 5/8-inch transmitter) are identical except that a bias battery and resistance divider are provided in the photo-tube output circuit of the 18 5/8-inch transmitter. This allows the injection of a negative current into the modulator to zero the output on white copy for the transmission of negative copy.

The circuit diagram of the modulator is seen in the left center portion of Figure 6. The output of the fork oscillator is passed through a 3 kHz low-pass filter, FL705, and drives the primary of transformer, T201, in the modulator. The transformer, T201, has a 10 kΩ primary and a balanced 10 kΩ secondary with a center tap. A double static shielding is employed to minimize capacity feed-through in the transformer. Since the secondary of the transformer is isolated from ground, the photo-current introduced into the center tap of the transformer is effectively switched into the load resistors R310 and R313. During the positive half cycle of the 2.4 kHz drive signal, terminal 4 is positive with respect to terminal 6, and a low impedance path is provided via CR301, R305, R306, and CR302. Since CR301 and CR302 are matched diodes, and R305 and R306 are 1% resistors, a minimum amount of 2.4 kHz drive appears across R310. Thus, the voltage across R310 is primarily due to the photo-current. Likewise, during the negative half cycle, a conducting path is formed via CR304, R308, R307, and CR303, switching the photo-current into R313 during this period.

Although balanced diodes and 1-percent resistors are employed in the modulator, additional balance is required for satisfactory operation. The added balance is provided by R309, R314, R315, and C301. The adjustment of R314 and R315 allows the injection of two nearly orthogonal balance voltages into the load-resistor circuits via R311 and R312 which are in series with the load resistors. Thus, the adjustment of R314 and R315, when the phototube is dark, enables complete cancellation of 2.4 kHz feed-through from the modulator drive.

e. Signal Amplifier

The modulator output consists of a low-level differential voltage with an output impedance of 1MΩ. For maximum utilization of this signal, a high-input-impedance, differential, FET amplifier was employed. In order to provide maximum common-mode rejection of unwanted signals from the modulator, a constant-current transistor is employed in the common-source leads of the differential amplifier, and a potentiometer is provided to adjust the dc operating points of the transistors. The single-ended output of the differential amplifier drives a low-pass filter with a 3.6 kHz cutoff frequency. The filter consists of a single constant K section terminated by two m-derived half sections to match the circuit impedance as well as provide 65 db attenuation of the 4.8 kHz second-harmonic signal generated in the modulator. A minimum of 28 db attenuation is provided for the frequencies above 4.8 kHz. The filter output drives a four-stage single-ended amplifier which is transformer-coupled to the single line. The ALC (Automatic Level Control) function in the amplifier is accomplished via a common collector transistor in the emitter circuit of the first amplifier stage which is bypassed by a capacitor and an FET. A two-stage amplifier is used to apply the ALC control voltage to the gate of the FET. A detailed description of the signal-amplifier circuit of Figure 6 or 7 is provided below.

The modulator output consists of a differential voltage between the two load resistors, R310 and R313, which is capacitively coupled into a high-input-impedance, differential, FET amplifier consisting of Q301 and Q302. The operating points for transistors, Q301 and Q302, are adjusted via R317. This adjustment allows a maximum common-mode rejection by providing equal ac operating points on the transistors. The adjustment is made in the initial fabrication and should require readjustment only when components are changed. The constant-current transistor, Q303, in the common-source lead of the differential amplifier is used to provide a maximum common-mode rejection from the amplifier.

The output of FL706 is capacitively coupled to Q401, the signal-amplifier input stage. The input stage is a common-emitter amplifier with a by-passed constant-current transistor, Q402, in its emitter circuit. Since Q402 presents a high ac emitter impedance, the gain of Q401 is a function of the impedance of C404 and Q403 which bypass the constant-current transistor Q402. Thus, the gain of Q401 is a function of the gate-to-source voltage, of field-effect transistor, Q403. With $V_{GS} = 0v$, the resistance between the drain and source terminals equals 200Ω while this value increases to 14 kΩ with $V_{GS} = 5v$. The control of the V_{GS} of Q403 provides the option of automatic level control, ALC, in the signal amplifier. With the ALC switch, S701 (on the internal panel), in the OFF position the value of V_{GS} is determined by the setting of R422 which is located on the amplifier board.

Operation in this mode essentially provides an additional gain control via R422. With the ALC switch in the ALC position, the value of V_{GS}, and thus the gain of Q401, is a function of the output-signal voltage.

The amplifier second stage, Q404, is capacitively coupled to the collector of the first stage via C403. This stage is a common-emitter amplifier with a 100Ω resistor, R412, in the emitter for gain stability and a 1.1k resistor, R413, bypassed by C405 for bias stability. The collector load resistor of Q404 consists of a pot, R411, located on the amplifier board. This provides an internal gain control. The output of Q404 is capacitively coupled to a break contact on relay K401 via the gain control, R411, and is capacitively coupled to the ALC amplifier consisting of Q405 and Q406.

The first stage of the ALC amplifier, Q405, is a common-emitter amplifier with an un-bypassed resistor, R419, in the emitter for stability. A gain control on this stage is also provided by pot, R420. This control provides a means of adjusting the maximum signal output when the transmitter is operated in the ALC mode. The output of Q405 is capacitively coupled to Q406, an emitter-follower amplifier. A diode, CR401, is provided in the base of the circuit of Q406, clamping the negative voltage at this point and preventing coupling capacitor, C410, from becoming charged to the peak voltage. The second ALC amplifier stage, Q406, is an emitter-follower to provide a low drive impedance to charge C406 in the gate circuit of Q403. Since the RC time constant of the circuit comprised of C406 and R414 equals 3.3 seconds, the ALC circuit allows a black page with white borders to be transmitted with a minimum of washout.

The output of Q404 drives an emitter-follower amplifier, Q407, via a break contact of relay K401. The emitter-follower provides a low drive impedance for the output amplifier but its primary function is to provide a relatively high impedance to the sync.-generator circuit. The output amplifier, Q408, is a common-emitter amplifier with the output transformer, T701, in the collector circuit. The output-level control, R601, functions by varying the amount of emitter-circuit degeneration. The output-level meter, M601, and the output-level control, R601, are located on the front panel.

f. Sync. Generator

The sync. generator provides for the synchronization of the transmitter and receiver preceding the transmission of copy. The sync. signal is generated by a light source and photodiode focussed at a point on the cylindrical surface of the rotor containing the crank-shaped illumination fiber. The rotor is painted mat black, with a small specularly reflective area at the position on the rotor which is opposite the photodiode

when the illumination fiber is at the leading edge of the copy. Thus, in operation, the reflected light illuminates the photodiode which shunts the 2.4 kHz from the oscillator to ground, providing a series of pulses of the carrier signal.

The sync. timer is included to provide an automatic transfer from the phasing mode to the transmission mode of operation. The duration of the phasing period is variable but is normally adjusted to be equal to the time for the copy to traverse the distance from the copy alignment stop to the scanning line of fibers. The diagram of the circuitry providing the timing function is seen in the lower right portion of Figures 6 and 7. The circuit, consisting of Q501, Q503, and Q504, is a one-shot multi-vibrator providing a 15 second pulse to operate relay, K401, during the phasing period. In the quiescent state, transistor, Q503, is saturated, receiving its base current via transistor, Q502, which is also on. Transistor, Q501, is held off since its base voltage is derived from the collector of saturated Q503 via a divider network. Upon depression of the START-STOP switch, S602, on the front panel to the START position, the base of Q503 is momentarily grounded, turning off Q503. The collector voltage of Q503 rises, driving Q501 into saturation and dropping its collector voltage to approximately 1.0v. Since the voltage at the collector of Q501 drops from +20v to 1.0v, the voltage at the gate of Q504 drops a corresponding amount, from +2v to -17v, as the voltage across C501 does not change instantaneously. Thus, Q502 is held off until its gate voltage rises to +2v. This period is a function of the time constant of C501, R502, and R503. Since R503 is a potentiometer, the period can be varied over a 2 to 1 range. When the voltage at the gate of Q502 rises to +2v, Q502 turns on, driving Q503 into saturation, and the circuit returns to its quiescent state.

g. Transmission Termination

The provision of automatic termination of transmission at the end of copy is complicated by the flat-bed feature of the scanner and unlimited copy-length capability of the transmitter. Due to the requirements for the transmission of large areas of black copy, the level of the signal output cannot be used as a reliable indication of end of copy. Thus, an optical sensor was employed at the end of the transport belt as seen in Figure 1. The sensor also provides an edge guide for copy alignment. The paper-out sensor consists of a light source and detector mounted below the scanner bed and a mirror mounted in the finger extending over the copy. The light from the lamp must make a double pass through the copy to the detector providing reliable operation for any basis weight of copy including translucent copy. Since the copy-out detection occurs at approximately four inches in front of the scan bar, a delay is required before the transmitter is to be turned off. In the

8 1/2-inch scanner, the delay is provided electronically, since the manual and slow-speed ranges are electrically controlled, rather than by a gear change. The circuit for the copy-out delay is seen in the lower right hand portion of Figure 6.

The circuit, consisting of transistors, Q504-Q508, comprises the paper-out time delay. With paper in the transmitter, photodiode CR702 presents a high impedance to the base of Q504 and, thus, Q504 is in saturation. Since the base of Q505 is directly coupled to the collector of Q504, transistor, Q505, is off. When the paper passes from the paper sensor, CR702 is illuminated, shunting the base of Q504 to ground and, thus, turning it off. The collector voltage of Q504 rises and drives Q505 into saturation causing the relay, K501, in its collector circuit to operate. Relay, K501, operates, removes shunt-to-ground across C504 and C505, and transfers +28v from the common terminal of S702 to contact 11 of relay, 702. Capacitors, C504 and C505, connected between the gate of Q503 and ground, begin to charge via R516 and R517. When the transmitter operates in the fast mode (180 scans a second), resistor, R417, is shunted. When the gate-to-source voltage of Q508 approaches 0v (2.5 minutes at 180 scans/sec.), Q508 begins to turn on, lowering the base voltage of Q506 and increasing its emitter voltage. As Q506 turns off, the rising voltage at its collector is capacitively coupled into the gate of SCR Q507. When SCR Q507 fires, it shunts the coil of relay, K702, to ground via its locking contacts, 12 and 6, and breaks contacts on START-STOP switch, S602. The SCR current is limited by resistor, R712, until relay K702 de-energizes, which opens contacts 12 and 6. At this time the RELOAD lamp lights, relay K703 is de-energized, transferring the signal-line terminals from the transmitter output to the telephone terminals, and relay K703 is de-energized. When relay, K703, drops out, terminals, J2-K and J2-L, and terminals, J2-J and J2-H, are opened, and power is removed from the motor-drive board, terminating the power to the motor.

C. MECHANICAL CONSIDERATIONS

1. Design Tasks

The principal mechanical design tasks were the following:

a. provide a uniform advancement of the copy under the scan-bar,
b. provide uniform rotation of the scanning crank-shaped fiber,
c. provide mechanical drive system and change of scanning speed in the 18 5/8-inch transmitter, and
d. provide the supporting structure and housing for both the 8 1/2-inch and 18 5/8-inch transmitters.

Mechanical design drawings of the 8 1/2-inch and 18 5/8-inch Fiber-Optics Facsimile Transmitters are shown in Figures 9 and 10, respectively.

2. Flatbed Transport

The index of cooperation specified for the 8 1/2-inch transmitter was 264, and that for the 18 5/8-inch transmitter was 576. The dimension of the optical scanning spot measured perpendicular to the direction of scanning was specified as 1/96 inch; therefore, the copy must be transported at a continuous and uniform rate to provide 96 scans per inch of copy.

A flatbed transport system was selected for copy transport over a roll drive system to provide a system capable of maintaining a constant uniform contact of copy against the scan-bar and to provide the capability of transporting paste-up or non-uniform thickness copy. Previous experience in the use of roll-drive systems indicated that the running of paste-up copies or copies of varying thickness would cause skewing. In roll-drive systems, drive rolls are surfaced with an elastomer to provide a slip-free drive. But this elastic surface also varies in drive radius (when subjected to varying copy thickness or pressure from the corresponding pressure roll), producing non-uniform transport speed of copy.

The flatbed copy transport system consists of a flexible toothed belt reinforced by Fibrex (fiber glass) cables to maintain its dimensional stability. The belt is actually a wide timing belt. The belt is driven by a toothed roller the angular velocity of which is 1/576 that of the crank-shaped fiber in the 18 5/8-inch instrument, and 1/264 in the 8 1/2-inch instrument. An adjustable idler roller provides the belt tension required to maintain adequate copy contact against the scan-bar and adjustment for proper belt tracking. The outer surface of this belt was machine ground to insure flatness and uniform thickness so as to provide a constant pressure of the copy against the full length of the scan-bar.

3. Scanning

The scanning process is accomplished by means of a rotating crank-shaped fiber (Section II). It is imperative that the gap between the output end of the crank-shaped fiber and the circular array be maintained constant to within a total variation of less than 0.0005 inch to insure uniformity of illumination.

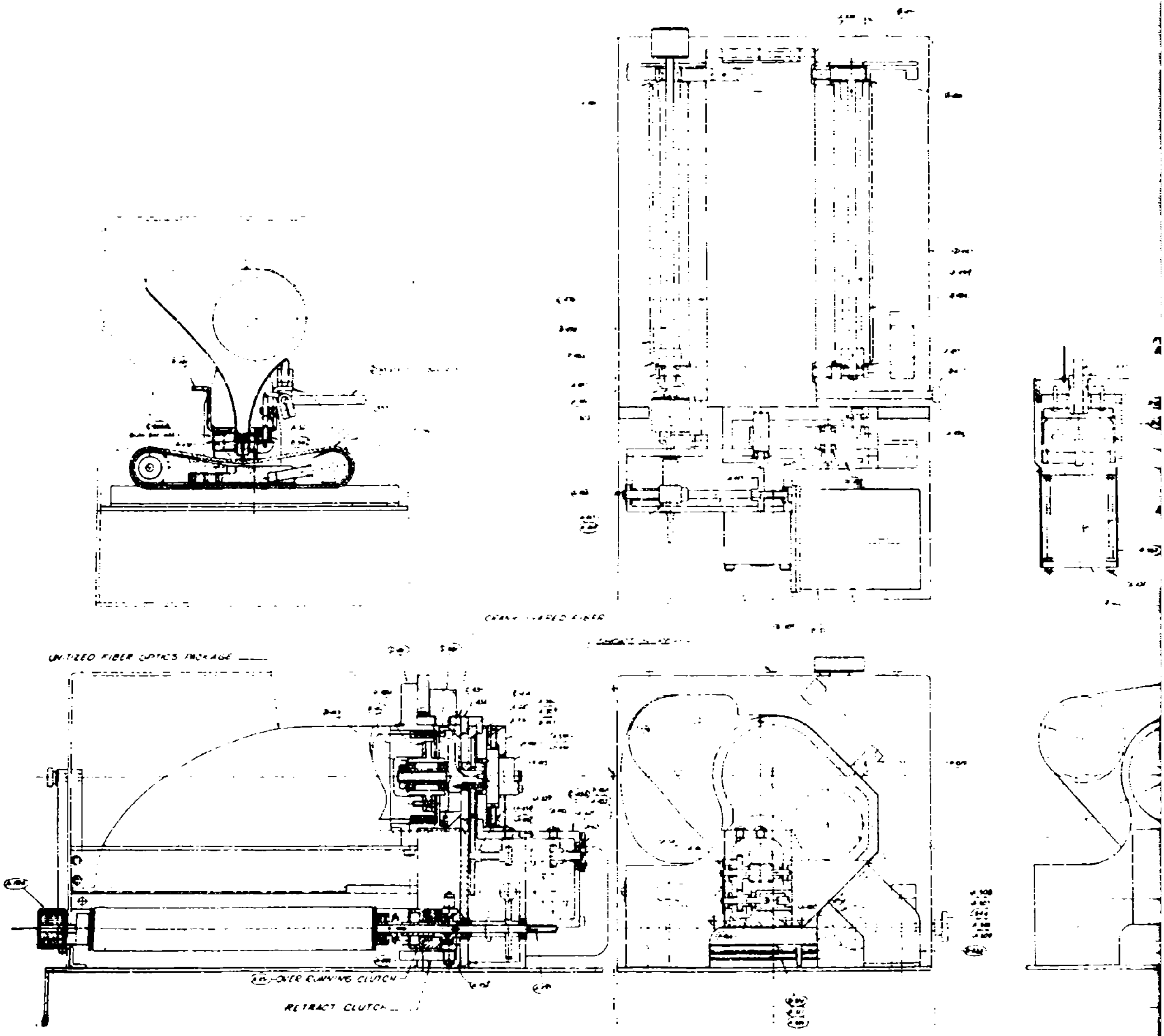
4. Mechanical Drive System

The mechanical drive systems for both the 8 1/2-inch and 18 5/8-inch transmitters are integrated drives of the crank-shaped-fiber component and the copy transport system. Mechanically, they are essentially the same except for the scanning speed change which is accomplished electronically in the 8 1/2-inch and mechanically in the 18 5/8-inch transmitter.

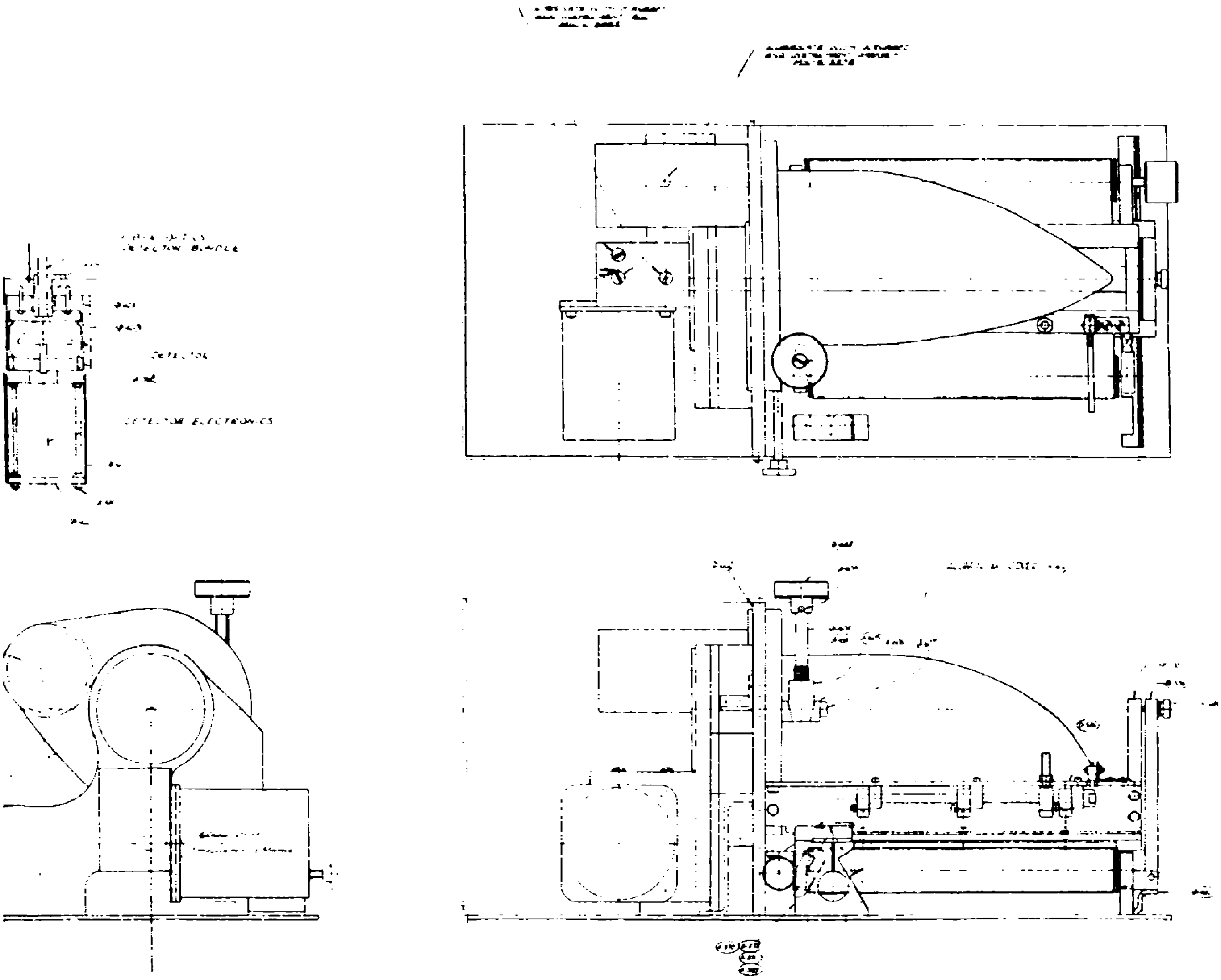
The drive system for the 18 5/8-inch transmitter is described here. This drive system delivers 60, 90, or 120 scans per minute across the copy, and advances the copy at a rate that will insure 96 scans per inch of copy. The system shown in Figure 10 is driven by a 3000 RPM hysteresis synchronous motor which is linked through a flexible coupling to a commercial speed-change box. This unit provides for a reduction in speed of 25:1, 33 1/3:1 and 50:1 which correspond to 120, 90 and 60 scans per minute, respectively. The unit delivers 100 inch-ounces of torque with a maximum backlash of 30 arc minutes through the gear train. The gear-change box is then coupled to a gear box that provides the drive to the crank-shaped fiber and the flatbed drive roll.

The drive to the crank-shaped fiber is accomplished through the use of two pairs of 90° helical gears, a connecting shaft, and two flexible couplings. This provides a folded configuration which reduces the overall size of the transmitter. The connecting shaft provides a separation point between the main drive system and the fiber-optics image dissector. This disconnect feature is required for the following reasons: The image dissector must be capable of rotation for periodic cleaning of the scan bar, and it must also be removable for inspection and/or replacement of the image dissector. The connecting shaft also allows for manufacturing variations, since exact alignment of the crank-shaped-fiber-drive assembly and the dissector circular array cannot be predetermined.

The housing for the crank-shaped-fiber drive is designed to be adjustable axially and angularly with respect to the circular array. A gap of approximately 0.002 inch must be maintained for adequate light distribution to the scan bar.



MECHANICAL DESIGN DRA
INCH SCANNER



SIGN DRAWING OF 8-1/2
SCANNER

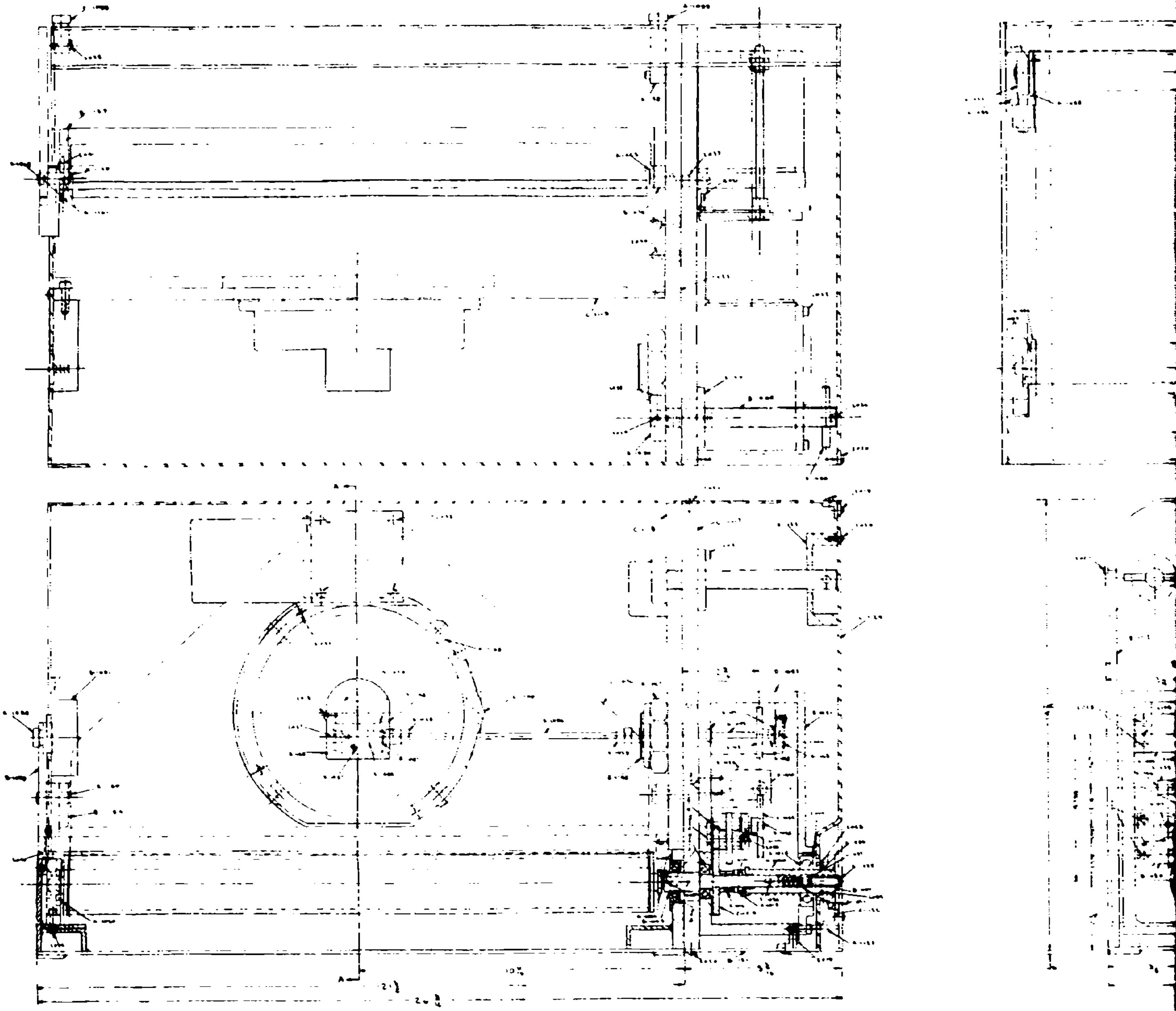
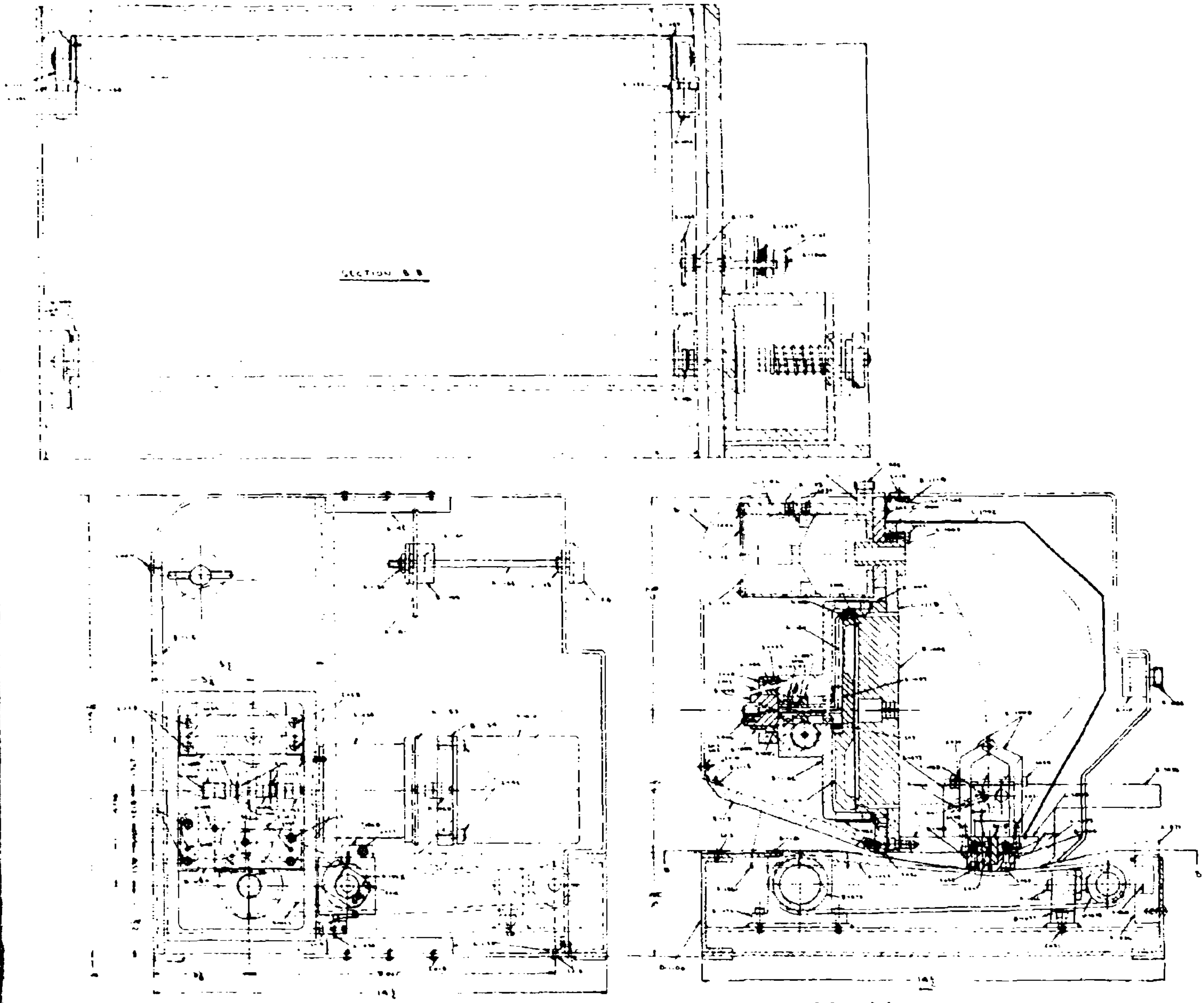


FIGURE 8. MECHANICAL DESIGN DRAWING 18 5/8



DRAWING 18 5/8-INCH SCANNER

The flat belt drive is driven from the same input shaft as the crank-shaped-fiber drive shaft. This is accomplished through a worm-gear drive coupled to two sets of spur gears. The total reduction in this system of 576:1 produces the required 96 scans per inch of copy.

The last gear is mounted to one half of a toothed coupling. The other half of the toothed coupling is mounted to a hollow shaft which is keyed to a shaft extension of the flatbed drive roll. This hollow shaft can be retracted by manually pulling the knob located on the outside of the housing. A ball detent retains the shaft in this position. This action disconnects the flatbed drive roll from the gear-drive position. The center button is manually pushed inward to re-engage the drive roll to the gear drive.

Precision gears manufactured to AGMA Class 11 specification were selected to minimize periodic torque variations.

5. Structure

The basic structure of both transmitters consists of three subsections: the upright section which houses the drive system, the base system which houses the flatbed conveyor, and the rotating section which houses the fiber-optics image dissector.

The upright section is securely fastened to the base section to form an L-shaped structure, and the rotating section is mounted to a bearing of the upright section which is concentric to the crank-shaped-fiber drive shaft. A hinged latch is mounted to the base section to maintain structural rigidity during normal use and during transport of the Facsimile Scanner. This latch is pivoted downward when a copy having a greater width than the transmitter is to be run.

IV. FIBER-OPTICS-SCANNER FABRICATION

The fibers used in both of the instruments have Schott F-2 cores and Kimble R-6 cladding. The diameter of the fibers is 0.0035 inch, and the thickness of the cladding is approximately 0.0002 inch. The refractive index of the core glass is 1.62 and that of the cladding is 1.52 yielding a numerical aperture of 0.56 and divergence angle of 34° in air.

Fabrication of a fiber-optics scanner starts at the drawing stage where the fiber diameter is controlled with high precision. In this application, uniformity of transmission is far more important than absolute transmittance and, consequently, every precaution is taken to insure a constant diameter. Great care is also exercised in winding the fibers on the take-up drum to produce a single layer of contiguous fibers.

After a layer of the required width has been laid down, the following technique is used to insure its integrity when removed from the drum. Aerobond epoxy is sprayed on the fiber across the width of the layer in two narrow bands separated by a narrow clear space. Other pairs of bands are applied wherever it is desired to cut the layer. When the resin is sufficiently cured, the fibers can be cut between the bonded bands, and the sheets removed from the drum.

Assembly of a fiber-optics scanner is an intricate task requiring the utmost of care and attention to detail. The procedure will be described only in broad terms. The end of one sheet is wrapped around a cylinder to which a thin layer of epoxy has been applied. The fibers are carefully lined up parallel with the axis of the cylinder and allowed to protrude slightly beyond the end of the cylinder to provide for subsequent grinding and polishing.

The ends of two other sheets are epoxied to the two halves, respectively, of the linear scan bar. When the epoxy is cured in each sub-assembly, the remaining linear end of the circular-to-linear array is epoxied to one of the halves of the scan bar, and the other half added to form the sandwich. The remaining uncemented ends of the two outside layers are now gathered together in one compact bundle, potted in epoxy, and inserted in the mechanical mount as shown in Figure 2. The final step is to grind and polish the different arrays using a number of specially designed fixtures for supporting and protecting the fiber-optics package during the operation.

The fiber-optics assembly is enclosed in a protective housing which, in the 8 1/2-inch instrument, is vacuum molded Royalite 20 plastic, and, in the 18 5/8-inch instrument, is sheet aluminum. The housing cavity is filled with Minit Foam in the 8 1/2-inch transmitter, and with lacquer-sprayed cotton batting in the 18 5/8-inch transmitter.

The crank-shaped fiber is heat formed to the specifications required by the mechanical design. It is then inserted in a slot provided in the rotor assembly and cemented in place. The diameter of the crank-shaped fiber, 0.015 inches, was made considerably over-sized for the following reason. A radially oriented slit (0.0035 x 0.015 inch) was formed on the distal end of the fiber by vacuum deposition of aluminum. A radially elongated spot of light is thus projected onto the circular array. In this way, fibers of the circular array which are slightly displaced radially will still be fully illuminated. The spacing between the crank-shaped fiber and the circular array is approximately 0.002 inch.

V. COPY SCANNING AND REPRODUCTION

The purpose of this section is to provide visual evidence of the capabilities of a Fiber-Optics Facsimile Transmitter. To accomplish this, several examples of working copy and their respective reproductions are included. These are explained and discussed. Obviously, displays which illustrate capabilities will also point up certain shortcomings and imperfections. These are also discussed along with measures needed for their elimination.

Figure 11 is a working copy containing both line patterns and continuous-tone gray scales and, therefore, is ideal for a general evaluation. Figure 11 was scanned and transmitted by the 8 1/2-inch Fiber-Optics Facsimile Transmitter developed on this program and recorded by a Photo Facsimile Recorder, Model RF16 (Times Facsimile Corp., New York), to yield the copy shown in Figure 12. Unfortunately, the transmitter and recorder have different scan intervals, approximately 10 mils and 8 mils, respectively, resulting in a foreshortening of the reproduction in a direction perpendicular to the scan lines. Overlooking this feature, it is seen that line copy is reproduced quite satisfactorily with good contrast and resolution; whereas the continuous-tone copy is reproduced with some obvious streaks and non-uniformities.

The latter are probably due to slight variations in photometric efficiency of the fiber system across the scan line which, in turn, is a function of several parameters associated with the fibers, themselves, and the energy transfer between components in the optical train. Among these parameters are:

1) Fiber variations.
2) Fiber ends chipped during grinding and polishing operations.
3) Fiber-end polish non-uniformity.
4) Fiber ends rounded from polishing.
5) Unequal spacing of fibers in different arrays.
6) Variations of copy-to-scan-bar spacing.
7) Areal-sensitivity variation of photo-detector surface.

The first five of these are intimately associated with the techniques of drawing and finishing fibers and fiber arrays. Great care is exercised to insure a uniform fiber diameter, e.g. rejection of fibers in the early part of a run until all factors have become stabilized. In spite of precautions, some variations are to be expected. Chipping of the end of a fiber by grinding and/or polishing reduces the effective aperture of the fiber and, therefore, its transmission. Since the glass fibers are supported in a resin matrix which is softer than glass, the system poses a

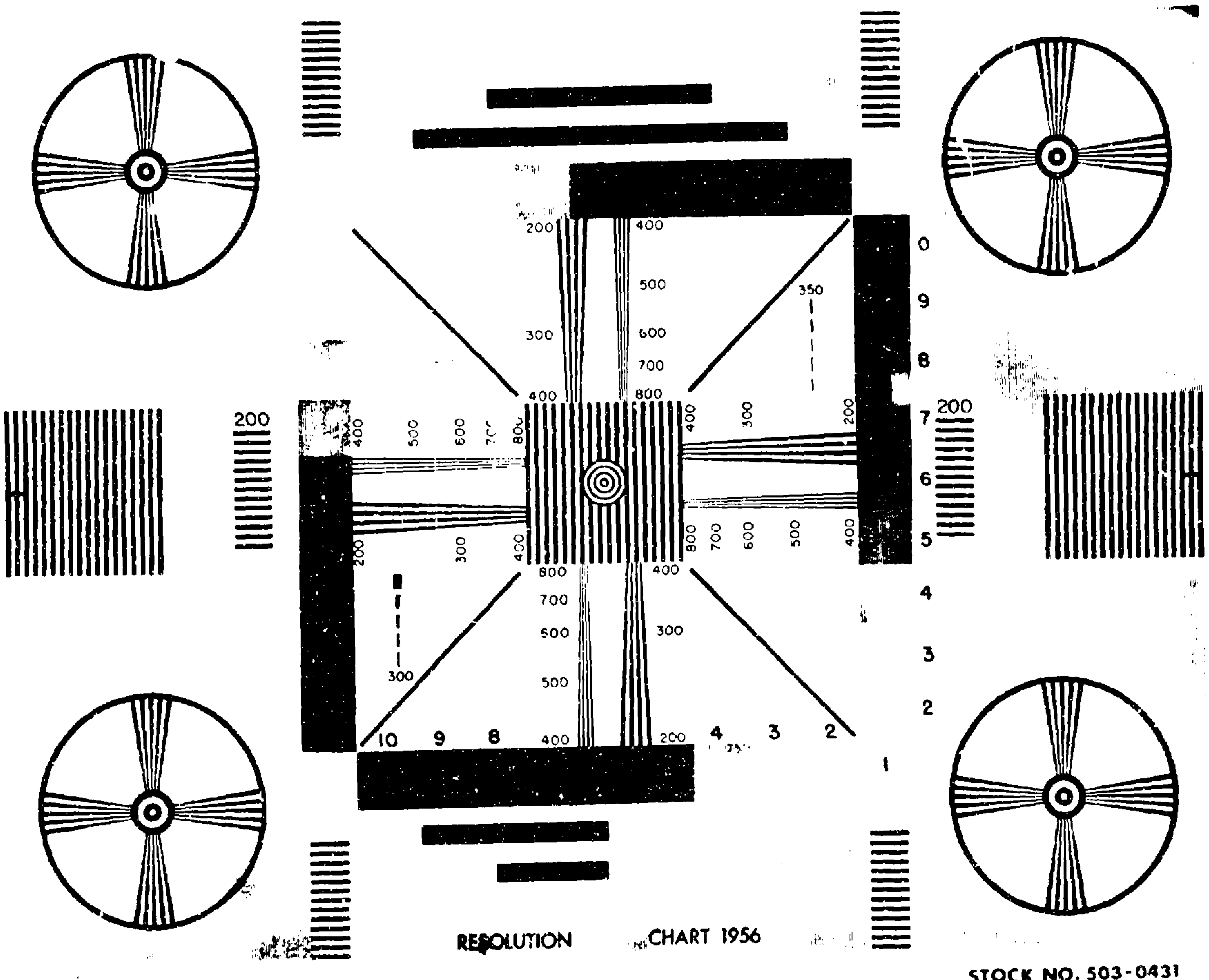


FIGURE 11. WORKING COPY

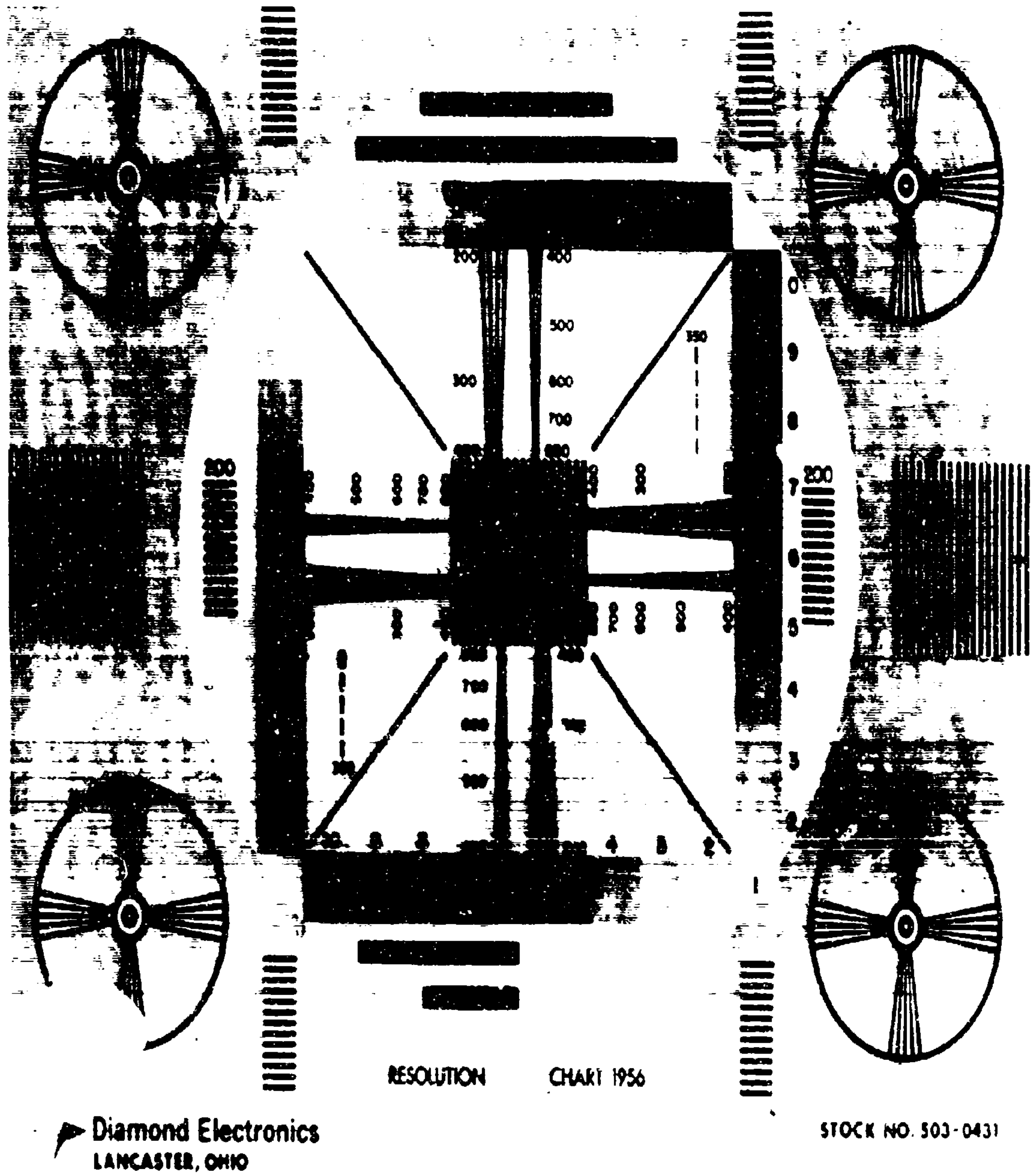


FIGURE 12. REPRODUCTION OF FIGURE 11 ON
8 1/2-INCH FOFT AND PHOTO FACSIMILE RECORDER RF16

unique and difficult problem as regards grinding and polishing. The resin tends to grind down faster than the glass fibers resulting in an uneven surface with the glass protruding slightly above its surroundings. Chipping of the edges and slight rounding of the ends of fibers are natural consequences and impossible to avoid completely. Furthermore, it is very unlikely that this effect will be entirely uniform over a complete array.

In conventional finishing of optical elements there are well-established tests for the quality of a polished surface, but these cannot be readily applied to fibers. Variations in polish over an array will certainly give rise to variations of transmission. Uniform spacing of fibers in the arrays is accomplished in a single-layer winding operation which, although it has been developed to a high degree of refinement, is not absolutely perfect. Consequently, small variations are still possible.

Variations of copy-to-scan-bar spacing may be caused by copy irregularities such as thickness irregularities, wrinkles, and folds. Pressure between the transport belt and scan bar can be expected to reduce their effect but not to eliminate them completely. The areal sensitivity of the photodetector varies somewhat over the tube surface. The deleterious effect of this variation has been reduced by leaving sufficient spacing between the sensitive surface and the end of the fiber bundle so that each emerging cone of light will cover a significant area on the detector.

Figures 13 and 14 are reproductions of a newspaper and a gray scale, respectively, made in the same way as Figure 12. They are included as additional examples of the points discussed in this section.

1,200 GIs Patrol S

U.S. TROOPS ARE MOVED TO BALTIMORE

2,000 Unable to End Rioting

Looting and burning continued yesterday in the fourth day since the assassination of Dr. Martin Luther King in various cities across the nation. The details:

Baltimore

(From Tribune Wire Services)

Baltimore, April 8 [Monday] --Despite the presence of 2,000 federal troops, sent into the city last night by President Johnson to help put down rioting, gangs of vandals tossed gasoline bombs and looted stores early today for the third straight day.

The decision by President Johnson to order in the 2,000 airborne troops was reached after Gov. Spiro T. Agnew declared the city in a state of insurrection.

Mayor Thomas J. D'Alesandro III said several hundred guardsmen, 300 state troopers, and 1,200 city police were aiding the federal troops.

Looting Is Widespread

The mayor said looting had increased in the western part of the city with 36 more fires reported. He said one of the major problems in bringing the disturbance under control was that the looting and fires were in many different areas.

At least four persons were killed and more than 400 injured. A 4 p. m. curfew ordered yesterday was strictly enforced by police and federal troops. Courts operated around the clock in an effort to process the more than 1,200 arrests. ... violence broke out in Baltimore Saturday. An unofficial count early today placed the number of fires at 415, the ... of stores looted at 100.

Pittsburgh

Pittsburgh, April 8 [Monday] ... National guardsmen and ... and city police restored relative calm to the city's Ne... district late last night after three days of widespread ...

[Continued on page 5, col. 1]

THE WEATHER

MONDAY, APRIL 8, 1968

CHICAGO AND VICINITY: Partly sunny and cooler today, high in upper 50s; fair and cooler tonight; low, in the ...; westerly winds 15 to 25 m. p. h. Tomorrow: Partly sunny with little temperature change.

NORTHERN ILLINOIS: ... [illegible]

WEATHERMAN'S RECORD [illegible]

NATURE NOTES

HONOR DR. KING IN CHURCHES

Quiet Crowds Attend Memorial Rites

WIDOW LEADS MARCH

Widow of Dr. Martin Luther King to lead memorial march in Memphis. Story on page 3.

BY DONNA GILL

The humming turned into song, and the notes and words of "Swing Low, Sweet Chariot," softly echoed thru the First Unitarian church.

The congregation, one composed of many races, had come for a common purpose—to worship on Palm Sunday and to honor Dr. Martin Luther King Jr.

Not everyone knew all the words, but from a corner of the gothic structure came the crystalline, proud voice of a Negro woman. The others joined in.

Churches thruout the Chicago area held memorial services for the slain civil rights leader yesterday.

Worshipers Are Subdued

Worshipers in the Unitarian church, 57th street and Woodlawn avenue, were subdued as they paid tribute to Dr. King thru song, scriptures, sermons, and silence.

In the beginning, it resembled any church service. A crying child, clutching a red toy rabbit, was taken from the church until he stopped his noise. The children's choir and the adult choir filed down the long aisle to the front, their voices raised in song.

The hymns they sang, the keyed to one man, were not nearly as striking as their actions. Black families and white families sat together peacefully; a white woman helped a black woman off with her coat; children of all races in the choir whispered back and forth.

Integration "Not Enough"

Madison St. a Bl... Scar in Heart of C...

BY ROBERT WIEDRICH

It was the crucifixion of a city, with Madison street the blackened, still smoldering nail that had been driven into its heart.

In the block just east of Homan avenue, the torch of the arsonist had done its worst work.

Hardly a building stood untouched.

It was as tho a giant flame thrower had played up and down the street, burning out roofs and crumpling walls until they arched inward to meet the heat-blackened, twisted steel structural members that hung into the ruins.

Flames Flicker On

Low, orange flames still flickered in the ruins of one building on the north side of the street. Only a few feet away a broken water line gushed a fountain toward the sky. The water served to protect a few square feet of flooring that protruded from what had once been the second floor.

And down in the first floor ruins, the flames fed on a dirty flowered house dress and what had once been a child's chair. The fire was consuming the bright enameled paint that decorated the broken chair in carefree patterns.

This was the west side of Chicago, where for nearly 48 hours virtually uncontrolled rioting and looting had raged in the glare of burning buildings.

Now the area was relatively quiet with only the curious and armed, uniformed men to observe the scar that had been slashed across the center of the city.

The national guardsmen and police were edgy, understandably so.

A sergeant of police, his blue ...

Chicago area residents and agencies offering help.

...helmet pulled down almost to ... his brow, drew his revolver and held it at the ready as a reporter approached in a car.

"Next time, don't come up on me so fast," he said. He didn't smile.

Down the street, a crew of city workmen wearing construction helmets busied themselves clearing wreckage from the street so covered with broken glass that it glittered in the sunlight like a ... piece of carpeting.

A clean, shiny fire engine was parked on the north side of the street, its fireman polishing the bright brass ... with a cloth while two of ... crew were lifted to the second floor level of a commercial building in the jaws of a ... city bulldozer.

Flames still flickered in the ruins, too. The two firemen crept along the charred flooring and began hacking away with axes at the wooden lathing that had been exposed by fire.

Watch for Snipers

A squad of guardsmen with rifles and carbines held with the butt plates on their hips stood across Madison street watching the firemen disinterestedly. The sun shot sharp rays of light from the brass clips of ammunition fixed to their ammunition belts.

Now and then one of the guardsmen stepped from the curb into the street and surveyed the ruined structures, apparently in search of snipers.

But there was only a strange stillness in the block. ... and then by the back of ... the firemen ...

Features

Bridge by Goren	Sec. 2, p. 10	Tower Ticker	Page ...
Classified Ads	Section 3	Washington Report	Page 10

FIGURE 13. REPRODUCTION OF NEWSPAPER ON 8 1/2-INCH FOFT AND PHOTO FACSIMILE RECORDER RF16

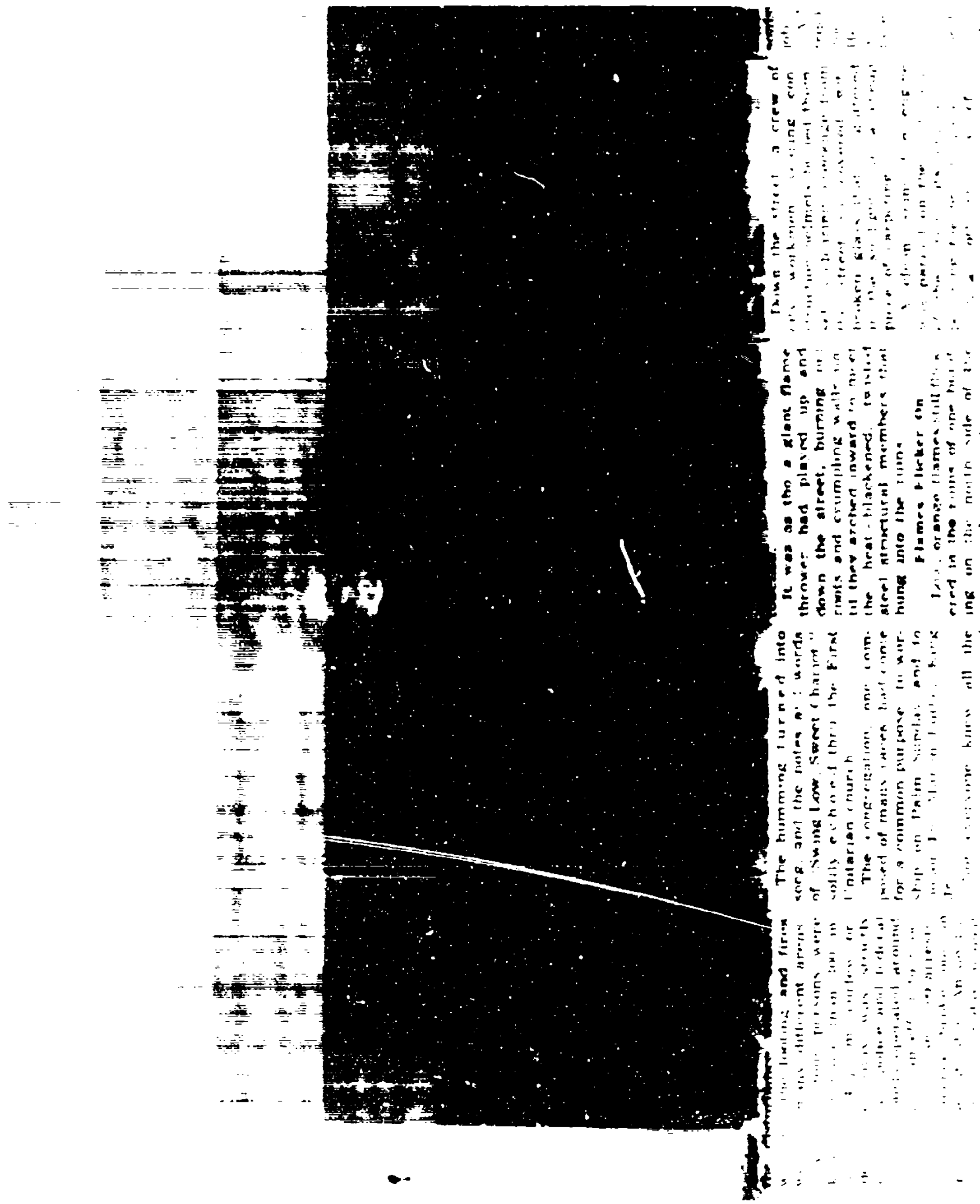


FIGURE 14. REPRODUCTION OF GRAY SCALE ON 8 1/2-INCH FOFT AND PHOTO FACSIMILE RECORDER RF16

VI. ENVIRONMENTAL TESTING

An environmental test program was conducted to determine the resistance of the fiber-optics components of a Facsimile Transmitter to deleterious effects of natural and induced environments peculiar to military operations. The test package consisted of the fiber-optics components of the 8 1/2-inch Facsimile Transmitter.

The test package withstood the various environmental tests extremely well. Breakage of fibers, in the few instances when it occurred, was attributable to failure of auxilliary components rather than to inherent properties of the fibers. The program, furthermore, provided valuable design data and materials criteria for future fiber-optics devices.

A complete discussion of the environmental testing and results are given in IITRI Report No. V6015-48 dated June 14, 1968.

VII. INSTRUMENT SPECIFICATIONS

Two Fiber-Optics Facsimile Transmitters were developed and delivered on this program.

Their specifications are listed below:

	8 1/2-inch	18 5/8-inch
Length	20 1/2 inch	26 5/8 inch
Width	10 1/4	14 1/2
Height	12 5/8	15 1/4
Weight	50 lb.	118 lb.
Scanning Rate	90,180/min.	60,90,120/min.
Scans per inch	96	96
Copy width	8 1/2 inches	18 5/8 inches
Copy length	Any length	Any length
Index of Cooperation	264	576
Output Signal Carrier	2400 Hz	2400 Hz
Operating Voltage	24-30 v. dc	24-30 v. dc
Operating Power	60 Watts	60 Watts

VIII. CONCLUSIONS

The two Fiber-Optics Facsimile Transmitters developed on this program have served to establish a number of advantages of the fiber-optics concept over more conventional approaches. The flatbed design and open-throat construction remove most of the restrictions on size and shape of copy which can be accepted. When the copy must be wrapped around a drum and clamped, the copy dimensions are severely restricted. The Fiber-Optics Facsimile, on the other hand, can scan copy of any length continuously, and the open throat allows wide copy to be fed through the instrument.

Inherent, also, in the fiber-optics-facsimile system is its capacity for uniform flux distribution and constant resolution across the entire width of the scan line. Because of the simiplicity of the fiber-optics system, the number of moving parts is reduced to a minimum, a rotating crank-shaped fiber and a copy-advance mechanism. Mechanical maintenanace is, accordingly, minimal. The system also has the potential for high-speed scanning and transmission. The instruments developed on this program were constrained by the requirement that they be operable over telephone transmission lines. Without this constraint, scan speeds 40 to 50 times greater would be entirely possible.

Finally, it has been established that the fiber-optics components of the instrument have the capacity to withstand thermal and physical environments normally met under natural and military conditions.

IX. RECOMMENDATIONS

Careful consideration of Section V of this report and a study of the reproductions shown in Figures 12, 13, and 14, lead to the inevitable conclusion that further work is needed. Although high-contrast copy, such as printed matter and line drawings, reproduces quite satisfactorily, it is obvious that reporduction of continuous-tone material leaves something to be desired.

It was pointed out in Section V that the high degree of uniformity of transmission required for satisfactory reproduction of continuous-tone copy is a most difficult goal to achieve. It appears that the only hope of reaching this goal rests to a large extent on a considerable refinement of the techniques of grinding and polishing fiber arrays and in a search for better materials for potting and containment of fiber arrays.

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11 SUPPLEMENTARY NOTES Report on design and construction of Fiber Optics Scanner	12 SPONSORING MILITARY ACTIVITY US Army Electronics Command ATTN: AMSEL-NL-A-2 Fort Monmouth, New Jersey 07703

13 ABSTRACT

Fiber optics has been successfully employed to perform the functions of image dissection and scanning in Facsimile Transmission. Two operational models have been developed and constructed on this program to incorporate the concept. One was designed to scan copy 8 1/2-inches wide, the other, 18 5/8-inches wide. Both instruments posses the unique capability of continuously scanning copy of any length. (U)

14

KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Fiber Optics	8	3				
Facsimile	8-9	8				
Scanner	8-1	2				
Continuous	8-1	1				

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